URBAN STORMWATER TREATMENT AT COYOTE HILLS MARSH

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URBAN STORMWATER TREATMENT AT COYOTE HILLS MARCH - DECEMBER 1986

In 1983, ABAG built a marsh in Southern Alameda County together with Alameda County and the East Bay Regional Park district to see how a marsh might act as a natural barrier and filter for urban runoff. Enclosed is the report on this unique demonstration project.

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Urban Stormwater Treatment at Coyote Hills Marsh – December 1986, Emy Chan Meiorin – Principal Investigator, Association of Bay Area Governments, 181 pages.

ABSTRACT. Three artificial marsh/pond systems with a combined area of 22 ha were studied during a two-year period for treatment and accumulation of urban stormwater pollutants. Twelve storms were monitored during the winters of 1984-85 and 1985-86. Marsh inflow volumes ranged from 1.3 to $6.9 \times 10^4 m^3$ per storm with peak flows reaching 9.8 m^3/s. Composite water samples collected during storms were analyzed for TDS, TSS, BOD_5, NH_3–N, NO_3–N, Kjeldahl–N, ortho–P, total–P, Cd, Cr, Cu, Pb, Mn, Ni, and Zn. Accumulations of heavy metals were monitored quarterly in marsh soils; root, leaf and seed parts of cattail (Typha latifolia) and bulrush (Scirpus robustus); and five fish species: Sacramento blackfish (Orthodon microlepidotus), carp (Cyprinus carpio), mosquitofish (Gambusia affinis), three-spine stickleback (Gasterosteus acculeatus) and sculpin (Cottus spp.).

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URBAN STORMWATER TREATMENT AT COYOTE HILLS MARSH FINAL REPORT

Principal Investigator
Emy Chan Meiorin

December 1986

This Project was funded in part by a grant from the California State Water Resources Control Board (SWRCB Contract No. 3-085-225-1)

ASSOCIATION OF BAY AREA GOVERNMENTS
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SECTION 1
INTRODUCTION

The Demonstration Urban Stormwater Treatment (DUST) Marsh at Coyote Hills Regional Park in Fremont (Alameda County), California was designed as a prototype system and research facility to study wetland creation for stormwater treatment in the San Francisco Bay Area. The design of the marsh was intended to test various system configurations for water treatment effectiveness, to maintain and enhance other uses of the area such as flood control and wildlife habitat, and to demonstrate the practicality of constructing a treatment wetland. While some design specifications have been investigated for wetlands that treat wastewater, virtually no information exists on design of stormwater treatment wetlands. Analysis of the effectiveness of the DUST Marsh will provide useful information on which to base future wetlands design and to determine the practicality of wetlands creation at other sites.

BACKGROUND

The ABAG Surface Runoff Program evaluated a number of urban runoff treatment methods ranging from public works practices to various types of treatment facilities. Of these, wetlands treatment offered an innovative and potentially cost-effective method for the cleansing of urban stormwater runoff.

A wetlands treatment system combines the features of a conventional wastewater treatment lagoon with a natural biological purification system. As the final step in processing surface runoff prior to discharge to the Bay, wetland systems can be effective in the removal of gross pollutants (BOD, suspended solids and some nutrients) and accumulating trace pollutants (such as heavy metals and organics). Wetland treatment capabilities are reviewed in "The Use of Wetlands for Water Pollution Control" (Chan et al, 1982).

Purpose

To study the applicability of wetland creation for stormwater treatment in the San Francisco Bay Area, ABAG, in conjunction with the East Bay Regional Park District (EBRPD), designed and constructed the DUST Marsh. The project location is shown in Figure 1. The project site is approximately 55 acres and it receives urban runoff from a 4.6 sq mi area within the City of Fremont, California.

The research and design of the DUST Marsh system was a part of ABAG's San Francisco Bay Areawide (208) Water Quality Management Program. The East Bay Regional Park District owns approximately 60 percent of the project site and manages the DUST Marsh site as part of the Coyote Hills Regional Park. The Alameda County Flood Control District (ACFCD) owns approximately 40 percent of the marsh site and retains authority over flood control operations in the DUST Marsh and Coyote Hills Park area.

ABAG Demonstration of Urban Storm Water Treatment Project, Fremont, CA

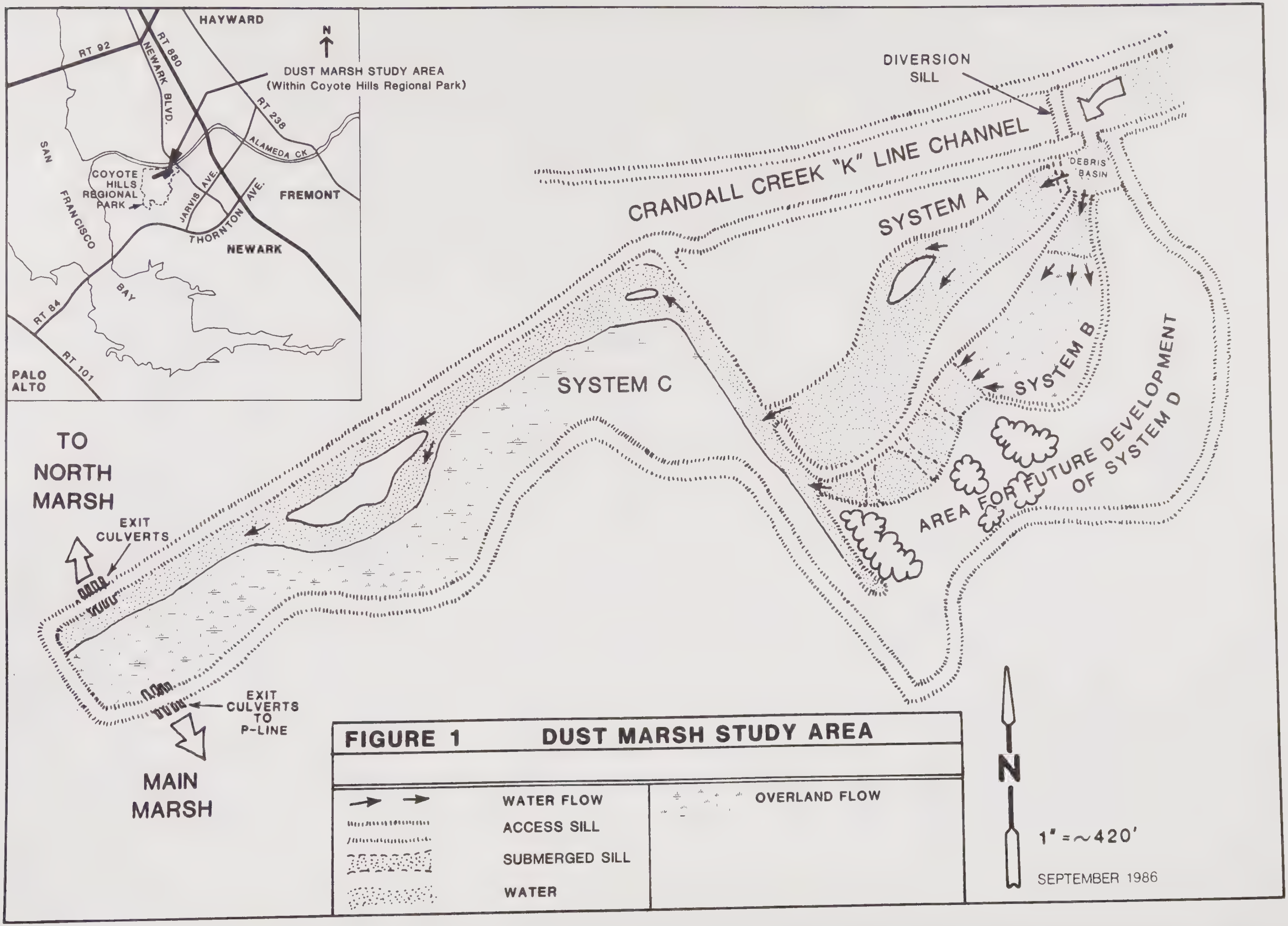


FIGURE 1 DUST MARSH STUDY AREA

The project design was financed jointly by a Clean Water Act - Section 208 grant and matching funds from ABAG and the park district. Construction funds were provided by an Environmental License Plate Fund grant administered by the California Department of Parks and Recreation. Funds to conduct the two-year monitoring program and to prepare this report were provided by a federal Clean Water Act - Section 205(j) grant administered by the California State Water Resources Control Board and by ABAG matching funds.

PROJECT DESCRIPTION

Overall Flow Pattern

Surface runoff from the Crandall Creek "K-Line" was diverted from the main channel near the northeast corner of the DUST project site, as shown in Figure 1. An earthen sill, constructed at elevation +5.0 ft. across the Crandall Creek channel, was designed to divert runoff volumes up to 490 ft^3/s (peak flow of the 10-year storm) into the DUST Marsh. The runoff water enters the initial Debris Basin and is then further divided among two parallel flow systems -- A and B. Each system contains different wetland types and may be operated independently. The two systems discharge into a common third system (System C), which eventually empties into the Coyote Hills North Marsh. A fourth system, D, has been planned to run parallel to System B with an inlet from the Debris Basin and an outlet into System C (see Figure 1). The construction grant was not able to cover the costs of building System D and separate funding is being sought to complete this system. The total marsh capacity (at elevation +4.0 ft.) is approximately 150 acre-ft.

In the event of a major storm -- magnitude greater than a 10-year storm or flows exceeding 490 ft^3/s -- the DUST Marsh would reach maximum storage capacity. At that time, K-Line flows would overtop the in-channel diversion sill and flow directly into North Marsh.

Each system was designed with shallow pond and channel margins to support seasonal marsh vegetation, as well as permanent pond and channel areas with 4 ft or greater depth to maintain permanent pools for mosquitofish. The ponds and channels are also intended to preclude overgrowth by cattails.

Debris Basin

Water from the K-Line enters the project at the 0.38 ac Debris Basin. The basin serves as a distribution structure for runoff flows into Systems A and B. Water flows out of the Debris Basin over two 60-ft wide concrete sills that hold back coarse floating and suspended material.

Due to the high percentage of fine silt in the runoff water, as observed during pre-design water monitoring, significant sedimentation was not expected to occur in the small debris basin. Sedimentation basins for pretreatment of runoff water were not practical in this project because the surface area needed to settle the fine silt would probably exceed the project area.

System A

System A contains a 5-acre lagoon system with a central island designed to increase water circulation. The pond margins were designed with a 1:4 slope to control the width of cattail growth along the banks. The lower margin of the System A pond adjacent to System C, was designed with a 1:10 slope to provide a broad "shelf" suitable for wetland vegetation. During stormwater runoff periods, this "shelf" area becomes inundated and the areal extent of surface water may increase up to 6 ac. The pond and island margins support cattail stands. It is anticipated that the large pond areas and thick stands of emergent and submerged vegetation will be effective at removing nutrients, mainly nitrogen, particulate matter and the associated bacteria and heavy metals.

System B

System B begins with a small initial basin that spreads water across the subsequent 4-acre overland flow area. The water then enters into a long narrow pond (1.68 ac) that is transected by three underwater sills. The sills are designed at 1.0 ft below the mean water level and will support narrow stands of cattails. Thus, water flowing through this pond will be "combed" several times by the linear cattail stands. The discharge from this pond flows directly into System C.

System B emphasizes a large overland flow area characterized by annual and perennial vegetation. Contact with the upper soil matrix, which supports plant roots and bacteria associated with the rhizosphere, hypothetically enhances nutrient and bacterial removal. Land-based treatment systems are generally more efficient than pond/lagoon systems for phosphorus removal due to soil interactions and the presence of phosphate-utilizing bacteria in the soil.

The cattail "sill" system was designed to increase the plant-water interface as compared to pond systems where contact with emergent vegetation occurs only along the pond perimeter. During the summer drawdown period, submerged pipes under the sills connect the pond cells to provide circulation and maintain mosquitofish access.

System C

This system covers 21 ac with a 45-ft wide by 0.5 mile long channel running the length of the system. The channel averages 5.5 to 6.5 ft deep and covers 11.6 ac. The remainder of System C is characterized by a broad flat overflow area thickly vegetated with cattails and alkali bulrush. During the stormwater flow periods, the water level can rise 1 ft and the water surface area extend over 16 ac. This system provides a large water-soil-plant interface with a large storage capacity capable of retaining stormwater for several days after a storm period. Water discharges from the west end of System C through a series of five 58-in. metal culverts under the northern boundary levee into the Coyote Hills Park North Marsh, and also through a series of three 36-in. metal pipes under the southern boundary levee into Coyote Hills Park.

System D

As planned, this system will contain a pond-overland flow-pond system with special considerations to protect existing willow groves and heron rookery. Due to a construction funding shortage, this system may be constructed in a later project phase.

FIELD SAMPLING PROGRAM

The primary objective of this project is to compare the treatment effectiveness of systems with various configurations and plant types in an artificially-created wetland. The basic sampling program, developed as marsh construction was being completed, focused on water, soil, plant communities and environmental fate of pollutants as described below:

Water Sampling Program

- Sampling of stormwater runoff flow and quality entering the DUST Marsh from Crandall Creek/K-Line channel,
- Sampling of flow and water quality leaving the DUST Marsh through exit culverts installed at the end of System C,
- Sampling of water quality at locations representative of the A, B and C Systems within the DUST Marsh during storms and intermittently during the dry season,
- Groundwater level observations and sampling at wells installed within the Systems A, B and C on a periodic basis, and
- Rainfall quantity analysis.

Development of Soil and Plant Communities

- Vegetation population analysis on newly-constructed overland flow section of System B,
- Experimental planting in the System B overland flow area and on submerged sills within lower pond of System B, and
- Soil sampling at representative vegetation locations within the newly constructed marsh systems.

Environmental Fate of Pollutants

- o Heavy metal analyses for cadmium, chromium, copper, lead, manganese, nickel and zinc contents of two plant species, by plant parts;
- o Heavy metal analyses of soil samples collected from three depths at the same locations as the plant samples; and
- o Fish sampling and heavy metals analyses.

SUMMARY OF DUST MARSH SYSTEM DEVELOPMENT AND TREATMENT PERFORMANCE

1. The DUST Marsh is a relatively young marsh system that has not yet reached equilibria between upland and wetland soils; and between marsh sediments and overlying water; vegetative growth covers 20 to 30 percent of the exposed land area in Systems A and B and has yet to reach a climax vegetative state. These are important considerations in evaluating overall system performance.

2. The DUST Marsh soils have historically experienced various conditions of flooding, saltwater intrusion and agricultural irrigation/leaching practices. The saline and sodic nature of these local soils have led to high mineral, nutrient and heavy metal background concentrations. Evaluation of stormwater pollutant contributions to marsh soils and sediments should be viewed in this overall context.

3. Stormwater inundation and flow over the new marsh system has had the apparent effect of drawing out accumulated salts and materials, as well as loosening up and suspending particulate matter from the soils. Mobilization of fine particulates in turn, liberates bound nutrients and heavy-metals. Thus, in the first few years of operation, we theorize that marsh soils should decrease in salinity while surface waters should exhibit increased salinity and soil-originated mineral, nutrient and heavy metal loadings.

4. The quantification and statistical verification of changes in soil parameters were difficult to perform as the variation within sub-systems was often greater than the variance between systems. However, the data on plant species succession provided an indirect basis for evaluating changes in soil conditions. During the first two years of operation, highly salt-tolerant plant species -- such as pickleweed, salt bush and fat hen -- were observed colonizing the new marsh site. In Spring 1986, after three years of stormwater inflow, the above three plant species have vanished and been replaced by mildly salt-tolerant species such as alkali bulrush, cattail and marshgrass. The shift in species implies a significant decrease in salt and mineral concentrations and provides a qualitative verification of the change in soil conditions.

5. The treatment performance of the DUST Marsh, over 7 monitored storms during Winter 1985-86 and on a seasonal mass loading basis, showed the

following removal rates: TSS, -64 percent (19,900 kg); oil and grease, -11 percent (15 kg); NO_3-N -15 percent (131 kg); Ortho-P, -56 percent (38.5 kg); chromium, -68 percent (10 kg); copper, -31 percent (1.6 kg); lead, -88 percent (1.56 kg); and zinc, -33 percent (6 kg). No detectable concentrations of selenium were found in the selection of water samples. Overall, System C, which supported a well-developed marsh system with mature vegetation provided the best treatment of metals, suspended solids and oil and grease. System A, the lagoon system, provided good treatment of suspended solids, ortho-phosphate and chromium. System B, the overland flow/pond system provided the best treatment of copper and NH_3-N.

6. During the Winter 1985-86 monitored storms, the following parameters exhibited increases in mass loadings: TDS, +49 percent (equivalent to 87,000 kg); BOD, +35 percent (370 kg); Kjeldahl-N, +28 percent (162 kg) and Manganese, +111 percent (197 kg). The increases in dissolved solids and manganese were greatest in System A and are probably due to saline soils and seepage of brackish ground water into the system. Organic material (BOD) increased the most in System A, which appeared to sustain greater algal growth and die-off due to the large volume of water and water surface area within the system. System B exhibited the greatest increase in organic-N (Kjeldahl-N) due probably to decaying organic material either deposited in the sediments or from algal material. System B also showed a significant BOD increase.

   Overall, the DUST Marsh was effective in the reduction of suspended solids, inorganic nitrogen, phosphorous, cadmium and lead regardless of system. As the marsh becomes more established, the differences in treatment levels between Systems A, B and C that are due to design variations will become more apparent; however, extrapolations on the magnitude of treatment improvement are difficult to make because variations in open water, and vegetated and bare ground areas. A follow up study in three to five years is indicated to verify the projected trend in system performance.

7. From soil data collected within each system and at two locations in the K-Line channel, heavy metal concentrations were comparatively higher in the K-Line channel adjacent to the Debris Basin and in System C. Both sites contain thick sediment deposits and support established mature vegetation; whereas Systems A and B are relatively new with poor soil development and only 20 percent plant cover on the exposed ground areas. Heavy metals in soils ranged from: chromium, 110-170 mg/Kg copper, 26-44 mg/Kg; lead, 16-45 mg/Kg; manganese, 29-1300 mg/Kg; nickel, 84-130 mg/Kg; and zinc, 59-100 mg/Kg.

8. Bioaccumulation of heavy metals in plant tissue was generally the highest in Systems A, B and the K-Line channel near Newark Blvd. Trace element levels and the concentration index (CI) plant metal conc. divided by soil metal conc.) were: chromium, up to 64 mg/kg dry wt and CI = .53; copper, up to 20 mg/kg and CI = .63; lead, up to 17 mg/kg and CI = 1.06; manganese, up to 1200 mg/kg and CI = 2.35; nickel, up to 47 mg/kg and CI = .43; and zinc, up to 81 mg/kg and CI = 1.37. The

highest plant uptakes did not necessarily occur in areas with greatest soil metals concentrations but instead correlated more strongly with areas supporting vigorous new plant growth.

9. Alkali bulrush (Scirpus robustus) and cattail (Typha latifolia) demonstrated significant uptake levels for all heavy metals. Overall, cattail exhibited the highest levels due to a combination of higher uptake rates in the leaf and seed tissues, greater storage in root and rhizomes and the highest biomass per sq meter (2 to 3 times more than bulrush). Scirpus uptake levels were generally one-third to one-half of Typha levels and are important in areas where Typha is less common.

10. As a biological removal mechanism for heavy metals in a wetland, Typha appears to be ideal. Given the appropriate range of conditions, cattails are able to grow vigorously, develop substantial biomass and bioaccumulate heavy metals beyond ambient levels. Unfortunately, cattails can grow so thickly as to inhibit water circulation and severely reduce habitat diversity. In flood control channels and some park and recreation areas, dredging and plant harvesting have been used to control cattail overgrowths. Harvesting of cattail plant material could also serve to remove the stored heavy metals. Periodic removal of cattail stands, thus, could serve the multiple purpose of improving water circulation, renewing plant growth in old cattail stands and increasing the pollutant uptake capacity of a wetland system.

11. Fish tissue analyses found significant bioaccumulations of chromium, copper, lead and zinc in blackfish and carp livers beyond the 85th percentile Elevated Data Level (EDL), a ranking system developed by the California Department of Fish and Game. No detectable concentrations of selenium were found in a selection of fish samples. Due to the high mobility and longevity (some specimens pre-dated the 1983 marsh construction) of these species, it cannot be determined if these fish picked up the contaminants in the DUST Marsh or the Coyote Hills Main Marsh. In general, regular human consumption of these fish would not be advisable. More studies are indicated to determine the range of heavy metals occurrences in blackfish and carp from nearby areas and to identify the actual sources of contamination.

12. The use of wetlands to treat urban stormwater runoff should be limited to constructed wetlands. Because the degree and significance of bioaccumulation of pollutants in the food chain is as yet unclear, such risks should not be imposed upon natural wetlands. Rather, these risks are more appropriately imposed on artificial wetlands where conditions may be better controlled and where periodic maintenance such as dredging or harvesting of vegetation would be acceptable.

13. Wetlands established for urban runoff treatment must be designed in full awareness of existing local conditions. As evidenced in the DUST Marsh, previous land use practices, such as farming, may leave higher than normal concentrations of various "pollutants" in the soil. When

this soil is exposed in a newly constructed wetland, these pollutants may actually be released into the stormwater until the wetland is fully stabilized. Similarly, pockets of brackish groundwater, present in shoreline areas, may actually contribute metals (manganese in the DUST Marsh) and other salts to the relatively fresh stormwater.

14. Further research should be conducted on the accumulation of various pollutants in the food chain. We recommend that heavy metals and toxic hydrocarbons be monitored in plants, invertebrates and fish for a period of several years in a wetlands treatment system. This research is necessary to determine the significance of metals amounts found in fish livers in this study.

15. The current DUST Marsh is far from being an established, mature wetland. With the current seasonal water supply and rate of plant growth, it will be another two to three years before the standing crop of vegetation could be considered heavy or typical. Since stormwater pollutant removal in a wetland is tied to the vegetation, we could expect that the treatment performance of the wetland for most pollutants will improve. We thus recommend that a conclusive study on wetlands treatment at the DUST Marsh be commenced in two years. The study should focus on selected pollutants considered harmful in San Francisco Bay nearshore waters - lead, chromium, copper, zinc, cadmium and toxic hydrocarbons (a subset of oil and grease).

16. Finally, this study began with the hypothesis that wetlands could provide water quality improvements to urban stormwater runoff. This study demonstrated that, in general, the quality of water passing through the DUST Marsh improved. Based on the data compiled in "The Use of Wetlands for Water Pollution Control" (ABAG, 1982), we remain convinced that as the marshland vegetation leaves the transitional stage and becomes fully established, water treatment capability will significantly improve. Thus, ABAG still recommends artificial wetlands as a viable urban runoff pollution control measure.

SECTION 2
MONITORING PROGRAM AND METHODOLOGY

STORMWATER FLOW MONITORING

Five stormwater flow monitoring stations, as shown in Figure 2, were established to obtain data for developing flow hydrographs. The station descriptions and monitoring methods are presented in Table 1.

TABLE 1. 1984-85 FLOW MONITORING STATIONS

Station	Location	Method
A-1	Inflow to System A at concrete entrance sill	Water depth + current measurements* at 5 locations across entrance sill
B-1	Inflow to System A at concrete entrance sill	Water depth + current measurements* at 5 locations across entrance sill
A-2	Outflow of System A to System C	Mid-channel water depth and current measurements* taken from a raft
B-2	Outflow of System B to System C	Mid-channel water depth and current measurements* taken from a raft
C-2	Outflow of System C 250 ft upstream of outlet culverts	Mid-channel water depth and current measurements* taken from a raft

* Water velocity was measured in situ with a pygmy current meter (Teledyne Gurley No. 625)

During each storm event, water velocities at Station A-1 and B-1 were measured at one-hour intervals. Station A-2, B-2, and C-2 flows were monitored at 2-3 hour intervals from a rubber raft. Periodic temperature and electrical conductivity measurements were also taken with a thermometer and portable conductivity meter (Hach Model 17250).

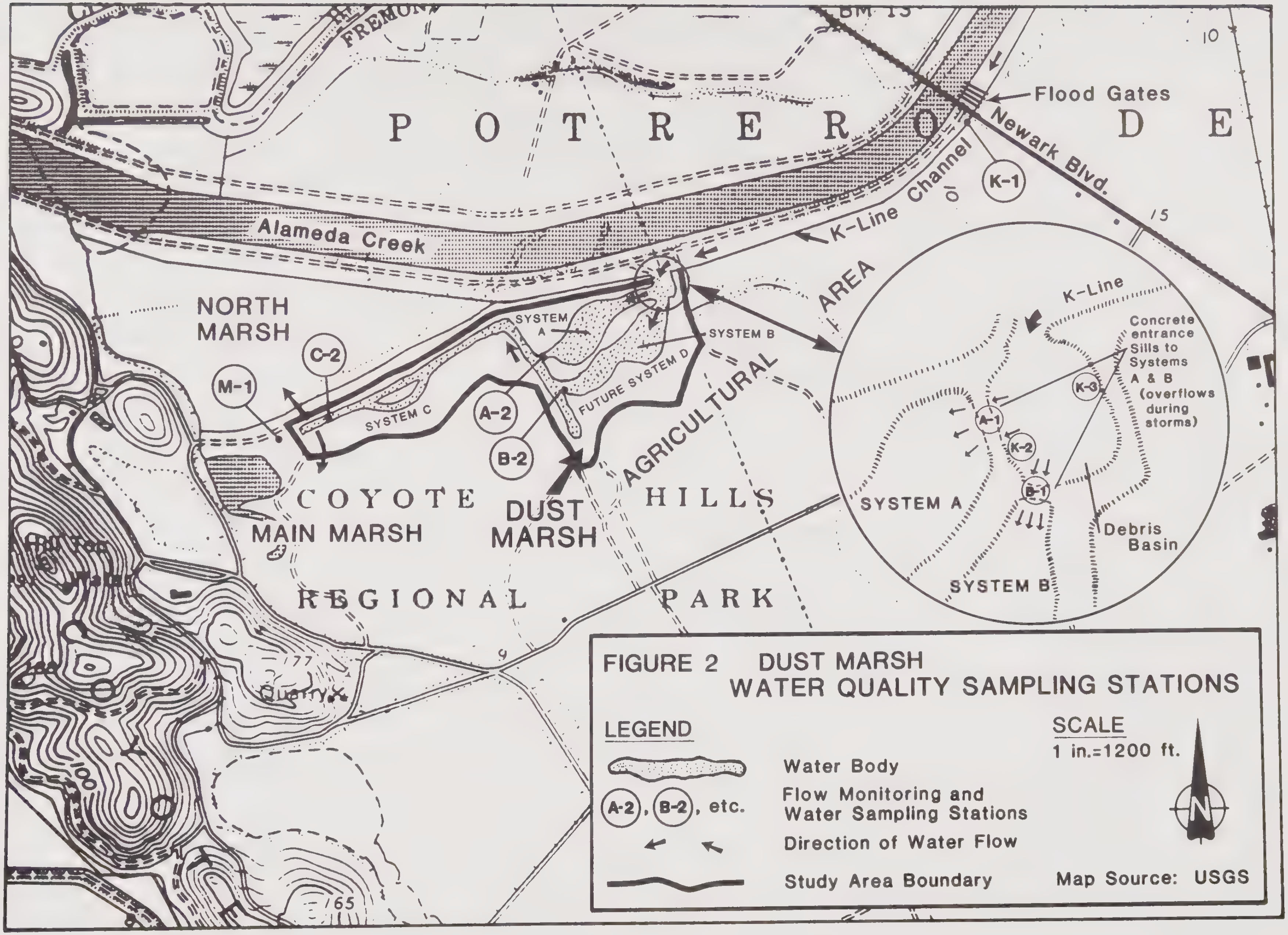


FIGURE 2 DUST MARSH
WATER QUALITY SAMPLING STATIONS

K-Line Channel Flows

Runoff from the Crandall Creek watershed flows into the K-Line channel, which runs adjacent to the Alameda Creek Flood Control Channel as shown in Figure 2. Approximately 500 ft upstream of the Newark Blvd. overcrossing is a series of eight 60-in. culverts connecting the K-Line channel with the Alameda Creek Channel. The culvert openings are controlled by slide valves, which are normally open year-around. Flap gates installed at the Alameda Creek end of the culverts allow K-Line flows into Alameda Creek, but preclude backflows into the K-Line when Alameda Creek water levels are elevated due to high stream discharge or tidal inflow. These gates were installed in 1975 to divert storm flows to Alameda Creek in the interim before the K-Line channel and Coyote Hills Ponding Area modifications to accommodate 100-year storm flows were completed. Under actual conditions, nearly all K-Line flows were bypassed directly out the flood gates and very little flow continued down the channel to Coyote Hills Park.

By the onset of the DUST Marsh research project, all the necessary modifications were completed and ABAG requested ACFCD to close the flood gate bypass. In response to potential downstream flooding concerns voiced by farmers, the Flood Control District directed the installation of a temporary sill in front of the flood control gates. The sill was set at a height of 2 ft so that normal daily flows would be diverted away from the flood gates, but peak storm flows would overtop the sill and discharge into Alameda Creek.

The status of the K-line diversion berm at the Newark Blvd. flood gates caused several problems during the Winter 1984-85 monitoring. The field conditions affecting marsh inflows are summarized in Table 2. The first diversion sill (earthen) was constructed in early November 1984. During the first monitored storm (12 Nov 84), the earthen sill breached during the peak discharge period and significant flow volumes escaped out the Newark Blvd. flood gate. Subsequently, a second sill of sand/concrete bags was constructed to replace the failed earthen sill. During the second monitored storm (27 Nov 84), several sandbags across the top of the sill washed out -- allowing minor flow losses. With the repair of the sandbags, low-to-moderate stormwater flows were confined to the K-Line channel, and only peak flows (greater than 2-ft height or approximately 30 cfs) crested over the sill. Thus, peak flow volumes observed at the DUST Marsh during subsequent storms were limited by the overflow function of the flood gate diversion sill.

TABLE 2. FIELD CONDITIONS AFFECTING MARSH FLOWS
DURING 1984-85 STORM MONITORING PERIODS

Storm Date	K-Line Diversion Sill at Flood Gate: Type	K-Line Diversion Sill at Flood Gate: Status at time T(hours)	Status of culverts from Debris Basin to Systems A and B	Discharge from farmer's field, T (hours)	Water Sampling Period, T (hours)
12 Nov 84	Earth 2 ft high	T10 eroded at 2 points, water flowing through T13 peak discharge begins, sill breached over 1/2 of length, water flowing out flood gate	open	T25 discharge begins	T15 to T26 (11 hours total) Stations K-1, K-2 A-2, B-2, C-2 Last sample taken as farmer's discharge begins
27 Nov 84	Sand/ concrete bags 2 ft high	T12 - T14 probable peak discharge period with overflow across diversion sill T20 small breach (4" x 6') in sill with overflow	open	T19 to T27 (8 hours total)	T4 to T27 (23 hours total) Stations K-1, K-2 A-2, B-2, C-2 Last sample taken as farmer's discharge begins
8 Feb 85	Sand/ concrete bags 2 ft high	T12.5 - T14 peak discharge period water cresting 0-4" over diversion sill	closed	No discharge	T12.5 to T46.5 (34 hours total) Stations K-1, K-2 A-2, B-2, C-2
5 Mar 85	Sand/ concrete bags 2 ft high	T14 - T16 peak discharge period, probable water cresting over sill	closed	No discharge	T12.5 to T46.5 (34 hours total) Stations K-1, K-2 A-2, B-2, C-2

Determination of System A and B Inflows

The inlets to Systems A and B from the Debris Basin were designed as 60-ft long by 20-ft wide concrete sills capable of providing access to maintenance vehicles in all seasons.

During the first two monitored storms in November 1984, frequent surface velocity measurements were taken at various water levels on the System A and B entrance sills. Since flow over the sills is a function of water level (head), a flow versus level correlation was sought for each sill. The combined flow over the two sills made up the total marsh system inflow.

The NGVD (National Geodetic Vertical Datum) elevations of the System A and B sills were surveyed along the entire length at 5-ft intervals. The cross-sectional sill areas are plotted against increasing water elevation in Figure 3. The flow rate, Q, was computed as the product of the sill area and the surface velocity. The resultant correlation of marsh inflow rate, Q, versus water elevation in the Debris Basin is presented in Figure 4.

In both of the above-mentioned figures, the data are divided into two time periods November-December 1984, and January 1985 and later. When the A and B sills were constructed in Fall 1984, the lowest point on the B sill was at elevation 3.32 ft -- nearly 0.2 ft lower than the A sill at 3.50 ft. During stormwater flow periods, this difference in entrance sill elevations caused 3 to 15 times as much water to flow into the B System than into the A System. The disproportionate flow made it difficult to compare the operation of the two systems. In December 1984, EBRPD directed the DUST Marsh construction contractor to build a 0.2-ft high concrete curb on the B sill in order to equalize the A and B sill elevations. In January 1985, the sills were resurveyed, and velocity rates were remeasured during February 1985. Flow volumes from the Debris Basin into Systems A and B are within 20 percent at elevations of 3.57 ft or higher. At lower elevations, between 30 to 90 percent more water flows into System A. Thus, for storms beginning in January 1985 through the Winter 85-86 season, the January 1985 graphs are applicable.

Pumped water from the agricultural drainage ditch adjacent to the Debris Basin contributed to the tail end of the stormwater runoff inflow at Stations A-2 and B-2. The occurrence of agricultural drainage water after the 1984-85 monitored storms is noted in Table 2. During Winter 1985-86, the farmers pumped infrequently after storms and generally did not interfere with storm flow measurements. In addition, 12-in pipes constructed under the System A and B entrance sills allowed up to 2 cfs of flow not accounted for when measuring sill flows. The condition of these pipes is also noted in Table 2. During Winter 1985-86, the pipes were continuously open and sill flows were adjusted to take this situation into account.

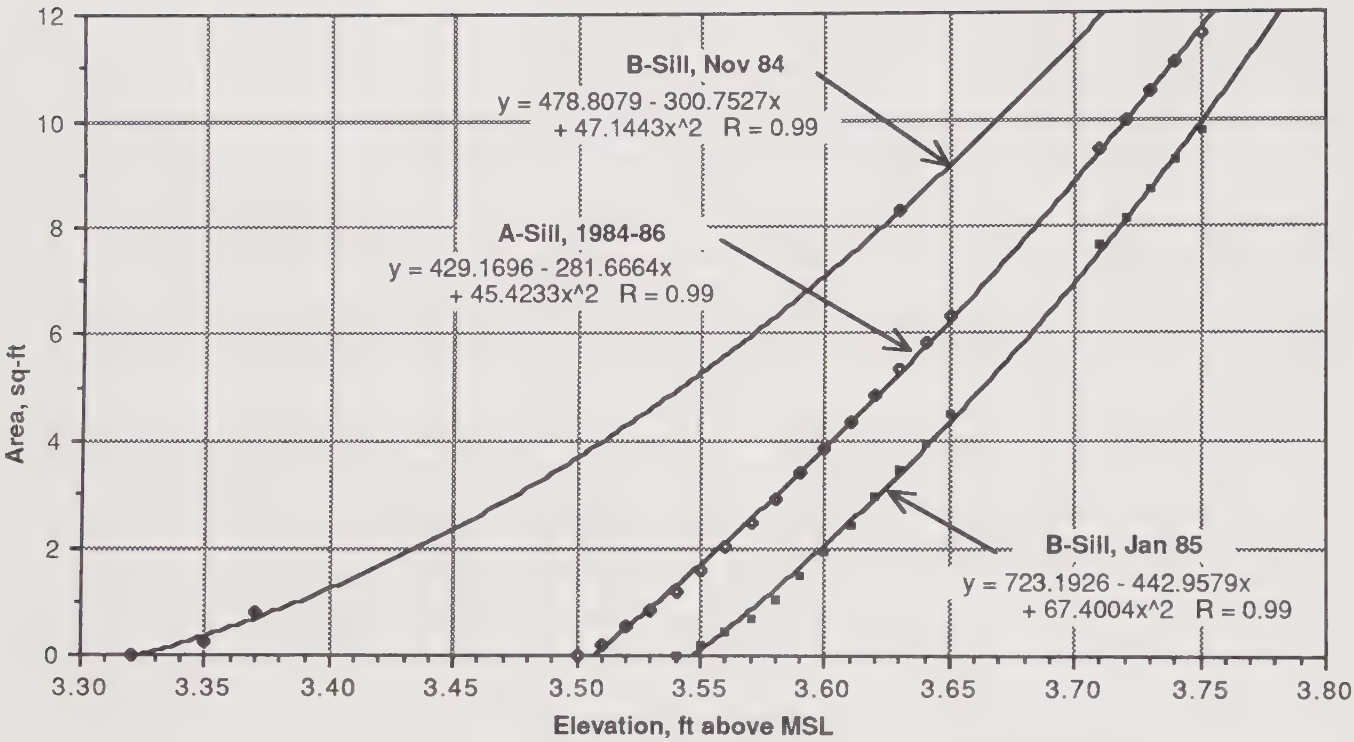


FIGURE 3. ENTRANCE SILL CROSS-SECTIONS

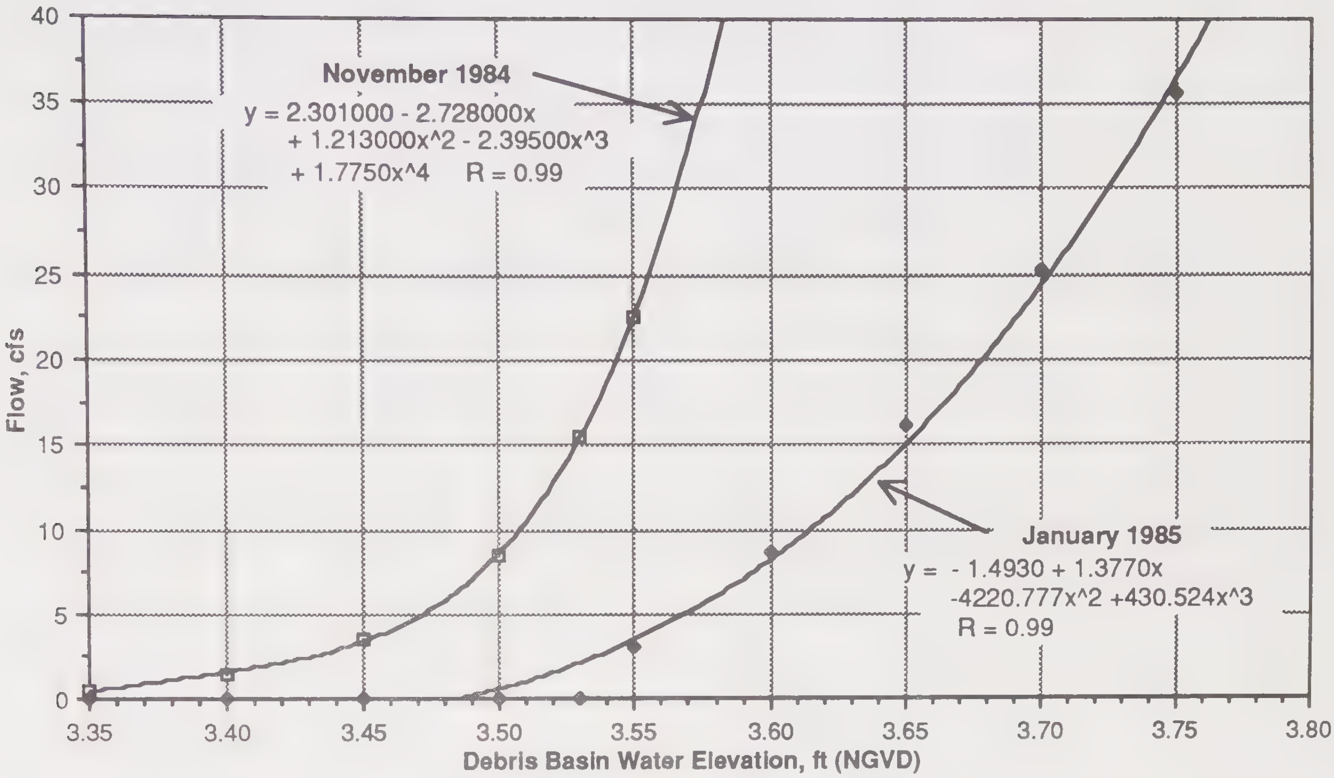


FIGURE 4. SYSTEM INFLOW RATE

Determination of System A and B Outflows

The System A and B outlets are 75-80 ft wide and vary in depth from 4 to 7 ft. Outflows from these systems were generally weak, meandering and difficult to measure -- particularly at night when no visual cues were available. One of the conclusions of the first year monitoring program was that a better system for measuring outflows at Stations A-2 and B-2 was needed. To solve this problem, the configuration of the marsh channels was reviewed carefully at these two stations and flow-concentration structures were designed to channel the meandering flows to points that were easily accessible for measurement. The flow-concentration structures consisted of semi-submerged wire mesh and fiberglass fences across each station with an 8-sq ft opening for outflows (see Figure 5). The stormwater monitoring program was revised to include the following:

1. Installation of a 7-day Richards-type water level recorder (Weathermeasure Model 6510) at Station K-2. Automation of monitoring at this station allowed field personnel to devote more time to the other stations.

2. Construction and installation of flow concentration structures at Stations A-2 and B-2 to facilitate measurements of slow and meandering flows. System outflows were channeled toward "gates" (8 sq ft openings) located 10-12 ft from the channel sides. Boardwalks were constructed over the water to allow access to all sections of the outlet gates. Water elevation staff gauges were installed on the boardwalk support posts at these stations. Extra field personnel were deployed at these stations during storms to obtain frequent flow measurements.

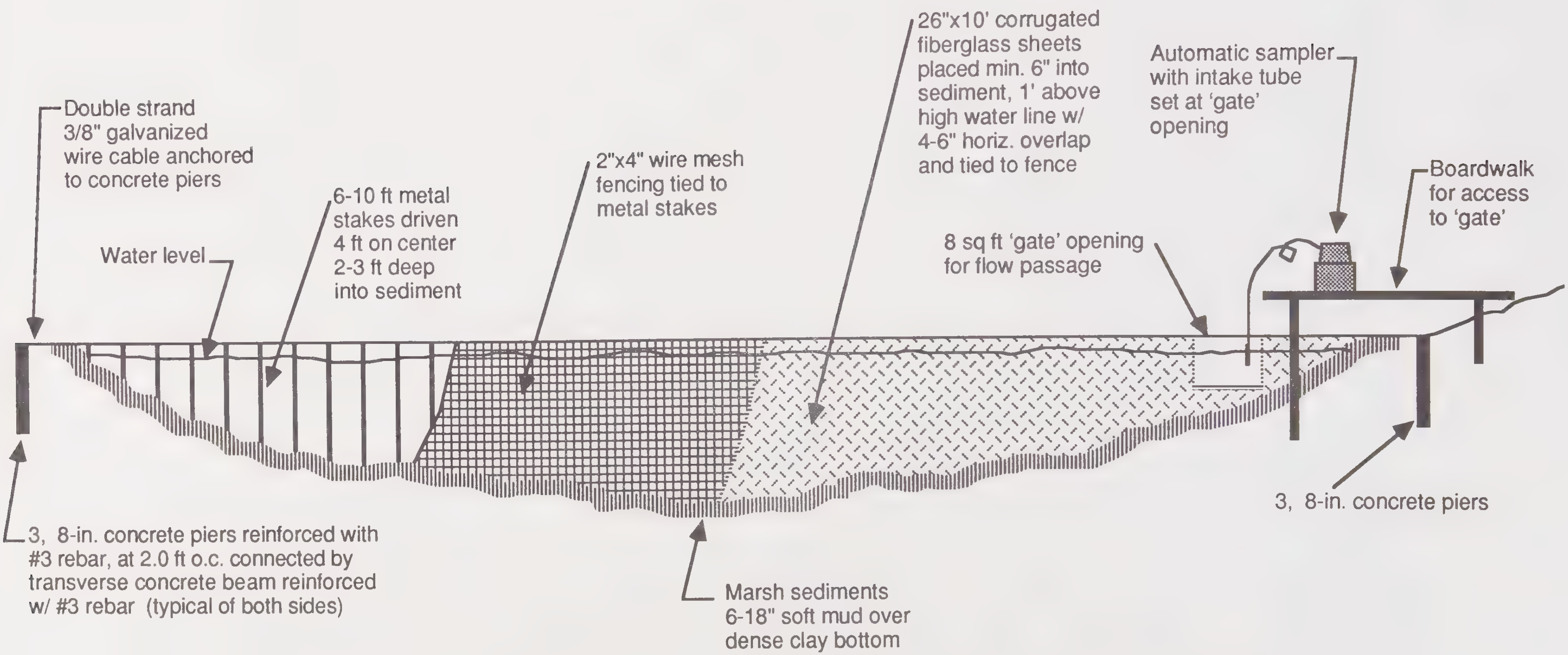
3. Continuous 24-hour monitoring by field personnel to cover Stations A-2 and B-2. Flow measurements were taken at the end of the boardwalks directly in front of the outlet gates with a photo-optical flow meter (Weathermeasure Model F-5 81-B). Water elevation to flow correlations proved to be unreliable when backwater effects occurred.

4. Construction and installation of a 3.5-ft weir on the west 58-in. outlet culvert at Station C-2. This culvert, the first in a series of four outlet culverts, is 1 ft lower in elevation than the other pipes and flows regularly only during storms. The weir structure facilitated flow measurements from this corrugated and irregularly-shaped pipe.

5. Installation of a water elevation staff gauge at the south end of System C where three 36-in. culverts connect System C with the P-line (southern drainage area). Elevation and flow measurements were taken at this station to supplement C-2 flow measurements at the 58-in. culverts.

FIGURE 5

FLOW CONCENTRATION STRUCTURES AT STATIONS A-2 AND B-2, TYPICAL CONSTRUCTION



Station A-2 channel width = 82 ft

Station B-2 channel width = 75 ft

TIME OF TRAVEL -- DYE STUDY

The configurations of Systems A, B and C were designed to be unique and as such, exhibit distinct flow characteristics. In all cases, the channel geometry is non-uniform, with flow complications such as islands, submerged berms and overland flow sections that make estimates of travel time by a conventional volume-displacement method highly variable.

To obtain a better understanding of the flow characteristics of the DUST Marsh, a dye-injection study was performed on 3 Feb 86. Based on methodology developed by Chase and Payne (1970) and reviewed by Kilpatrick (1970), the slug injection method using Rhodamine WT dye was selected. Rhodamine WT is more stable than other dyes in the surface-water environment, has low absorption loss and fluoresces at an unusually long wavelength that few naturally-occurring or industrial materials can reproduce. The dye is available as a 20% aqueous solution that is relatively easy to handle. The dye requirement computation was based on a final dye concentration of 0.05 ppm. This allowed for a 100 percent error that still met the detection limit of the fluorometer used to measure dye concentrations. The total dilution volume was based on an estimated total discharge of 1.3×10^6 ft^3 and a peak discharge of 30 ft^3/s.

Field Methods

The storm used for the dye study began at 0951 hrs on 3 Feb 86. The projected daytime peak flow times for the K-2, A-2 and B-2 Stations were ideal for the dye study as the dye could be visually tracked during daylight hours. At the Station K-2 peak flow period (approx. 1530 hrs), 9.5 liters of 20% Rhodamine WT dye (1.9 kg) was diluted into several buckets and simultaneously poured at several points across the entrance to the Debris Basin. The waters of the small Debris Basin were also physically agitated to ensure better dye mixing. Dye solution flows across the A-1 and B-1 sills occurred simultaneously within 15 minutes of initial injection.

Pre-dye-injection marsh water samples were obtained for background samples to calibrate the fluorometer. Flows were monitored frequently at all stations (see Runoff Flow Measurement section). Automatic water samplers (ISCO Model 1680) were set up at Stations A-2 and B-2 to sample at 30-minute intervals for the first 10 hours; and at hourly intervals thereafter. The sampler intake tubes were set near the mouth of the flow concentration gates at 6-12 in. below the surface. An automatic sampler was also set up at Station C-2 with a sample interval of every 2 hours. The automatic samplers were operated for 50 hours and were deployed again during the subsequent storms that occurred 9 and 11 days after the initial dye release.

Laboratory Methods

Water samples were transferred to 100-ml plastic containers and taken to a temporary storage area where a lab bench was set up with equipment to perform dilutions and prepare samples for measurement as needed. Samples were analyzed in one continuous time period with periodic temperature checks to ensure minimum temperature variation (coefficient of fluorescence = -2.6% per degree centigrade).

Dye concentrations were tested in a fluorometer (Turner Model 110), an instrument which measures fluorescence. The concentration of dye in a sample is directly proportional to the amount of fluorescence measured. The fluorometer was fitted with a far ultraviolet #110-851, T-5 lamp (narrow band 546 nm (nanometers)), a 546 nm primary filter and a 590 nm secondary filter. This combination met the 546 nm dye excitation frequency and detected the 570 nm light emittance frequency of the Rhodamine WT dye. The fluorometer was calibrated with prepared standard solutions down to 1 ppb. Fluorometer techniques followed Turner Designs (1980). Samples collected before the dye arrived at each station were tested in the fluorometer to determine background readings. These readings were subtracted from readings for subsequent samples, prior to determination of concentration. To test the effect of suspended sediments, several turbid water samples were read. Then they were allowed to settle for 24-48 hours and the clear supernatant measured. The change in fluorescence was negligible and reaffirmed the choice of primary and secondary filters together with the narrow band emitting lamp, which limited algal fluorescence and turbidity interferences.

STORMWATER SAMPLING

Wet season water quality sampling stations, as shown on Figure 2, were established at the following locations:

- K-1 K-line Channel 200 ft downstream of Newark Boulevard overcrossing
- K-2 Inflow to DUST Marsh Debris Basin from K-line Channel
- K-3 Inflow to DUST Marsh Debris pumped from agricultural area adjacent to System D
- A-2 Outflow from System A to System C
- B-2 Outflow from System B to System C
- C-2 System C channel 250 ft upstream of outflow culverts

During each storm, Stations K-1 and K-2 were sampled 10-20 ft from the side of the channel in areas with distinct flow and minimal emergent vegetation interference. Stations A-2, B-2 and C-2 were sampled in mid-channel from a raft equipped with an electric motor to minimize sampling-equipment related contamination sources. Station K-3 was sampled directly from the farmer's outfall pipe. The stations were sampled at approximately the same time -- within a 30-minute period coinciding approximately with the following five intervals:

1. Onset of stormwater runoff
2. Increasing discharge to system
3. Peak discharge period
4. Decreasing discharge to system
5. Resumption of normal system flow

The sampling intervals were determined by the sampling crew leader based on on-site flow measurements and their correspondence with a typical K-Line stormwater runoff hydrograph. During some storms, more than five intervals were sampled and the extra samples were discarded when the appropriate sampling periods were determined at the end of the storm. At each station, three mid-stream grab samples were obtained corresponding to:

- 1 coliform sample in a sterile bottle,
- 1 grease and oil sample in a solvent-rinsed bottle with a teflon-lined cap, and
- 1 sample for BOD, physical tests, nutrients, metals and residues

Collected samples were stored in light-shielded, insulated containers and transported to the analysis laboratory within 12 hours of the conclusion of the stormwater sampling event. In the situation where samples were held for over three hours from the collection time, the bottles were iced to retard biological processes and preserve the sample. All samples were clearly labeled with a waterproof ink identifying:

- sampling station
- collection time and date
- sample type (as appropriate)

At least once during each storm event, duplicate samples were collected at some stations, recorded and then submitted to the laboratory without station identification to serve as quality controls.

Requirements for the appropriate sample sizes, collection, handling, preservation and storage time limits conformed with the "US EPA Handbook for Analytical Quality Control with Water and Wastewater Laboratories" (1979). The water quality analysis parameters are presented in Table 3 and the laboratory analytical methods are presented in Table 4. Water analyses were performed on unfiltered samples to determine total pollutant concentration in the water as well as the suspended solids. BOD analyses were performed on filtered water samples to remove the gross effects of naturally occurring suspended algae.

TABLE 3. ANALYSES BY TYPE OF SAMPLE

Water	Soil	Plant and Fish
pH	pH	Cadmium
Conductivity	Conductivity	Chromium
5-day BOD	Chloride	Copper
Total Dissolved Solids	Exchangeable Sodium	Manganese
Total Suspended Solids	Cation Exchange Capacity	Lead
Oil and Grease	Orthophosphate	Zinc
	Total Organic Carbon	Selenium*
Fecal Coliform	Bulk Density	
Nitrate Nitrogen	Particle Size Distribution	
Ammonia Nitrogen		
Kjeldahl Nitrogen	Nitrate Nitrogen	
Orthophosphate	Ammonia Nitrogen	
Total Phosphorus	Kjeldahl Nitrogen	
	Ortho Phosphate	
Cadmium (Cd)	Total Phosphorus	
Chromium (Cr)		
Copper (Cu)	Cadmium	
Manganese (Mn)	Chromium	
Nickel (Ni)	Copper	
Lead (Pb)	Manganese	
Zinc (Zn)	Nickel	
Selenium (Se)*	Lead	
	Zinc	
	Selenium*	

* on selected samples

TABLE 4. ANALYTICAL METHODS FOR WATER, SOIL AND PLANT SAMPLES

Constituent	Analytical Method
Cadmium, Chromium Copper, Manganese, Lead, Nickel, Zinc and Selenium	Atomic absorption spectrophotometric method with nitric acid digestion for plant, soil and water samples. For low concentration of metals, the graphite furnace method was used for increased analytic sensitivity. Selenium = method 3050 (EPA 1984)
Total Phosphorus Orthophosphate	Ascorbic Acid (Method 424F with preliminary digestion, Method 424C) for total phosphorous phosphorus determination
Ammonia Nitrogen	Automated phenate method (417G)
Nitrate Nitrogen	Automated cadmium reduction (Method 418F)
Kjeldahl Nitrogen	Colorimetric semi-automated block digestion (Method 351.2) (EPA, 1979)
pH	Electrode (Method 423), on saturated paste for soil samples
Oil and Grease	Partition-Gravimetric Method (Method 503A)
Electrical Conductivity	Method 205, on saturated paste for soil samples
BOD	5-day bio-oxygen demand (Method 507)
Fecal Coliform Bacteria	Multiple Tube Test (Method 908C)
Total Suspended Solids	Method 209B: dried at 180° C
Total Dissolved Solids	Method 209C: dried at 105° C
Particle Size Distribution	Pipette gravimetric procedure
Exchangeable Sodium	Atomic absorption (Method 303A), following Ammonium acetate extraction (Method 9-3.1.2.3), (Page, 1982)
Chloride	Argentometric (Method 407A)
Cation Exchange Capacity	Ammonium Acetate Method (Method 8-3.3), (Page, 1982)
Organic Carbon	Combustion Infrared (Method 505), with preliminary oxidation of carbonates
Bulk Density	ASTM D2937, undisturbed core sample. (ASTM, 1982)

* Unless otherwise specified, all methods from American Public Health Association, 1985.

Winter 1985-86 Sampling Modifications

Based on the results of the first year's monitoring program, the sampling regimen was modified at several stations as summarized in Table 5. The focus was towards obtaining more reliable data for the K-2, A-2 and B-2 stations.

Stations equipped with an automatic sampler were sampled at 1-2 hour intervals depending on storm conditions. Station C-2 and oil and grease grab samples were sampled at the same frequency as the first year program. Sampling containers and storage methods were similar to the first year program with the exception of coliform samples which were discontinued due to the high variability and difficulty in calculation of mass loadings. At the end of each storm event, storm hydrographs were plotted at each station and samples were composited into the five time intervals corresponding to the first year program.

Dry Season Sampling

Dry season water quality sampling station locations were the same as the wet season stations with the addition of the following station for comparison purposes:

- M-1 Main Marsh approximately 300 ft southwest of earthen berm separating System C and Main Marsh

Grab samples were collected twice during the dry season corresponding to mid and late summer at Stations K-2, A-2, B-2, C-2 and M-1. The water quality parameters and procedures outlined in the wet season analysis were followed. Temperature and electrical conductivity were also measured *in situ* at various locations within the marsh. This was done in conjunction with other monitoring activities related to experimental vegetation planting and fish seining.

TABLE 5. SAMPLE METHOD BY STATION

Station	1984-85 Season	1985-86 Season
K-1 (K-Line channel at Newark Blvd.)	grab samples 10 ft from side of channel	no samples taken at this station
K-2 (Debris basin)	grab samples 10 ft from side of basin	hourly composite samples taken 10 ft from side of basin**
K-3 (Agricultural discharge to Debris Basin)	grab samples from end of discharge pipe	no samples taken at this station (discharge not operated during storms)
A-2 (System A outlet)	mid-channel grab samples (from boat*)	hourly composite samples taken mid-stream at outlet gate; grab samples for oil and grease
B-2 (System B outlet)	mid-channel grab samples (from boat*)	hourly composite samples taken mid-stream at outlet gate; grab samples for oil and grease
C-2 (System C outlet)	mid-channel grab samples (from boat*)	grab samples 10 ft from side of channel 100 ft upstream of discharge culverts

* Rubber raft equipped with electric motor to minimize sampling-equipment related contamination sources

** Samples taken with a multiple-bottle automatic sampler with intake set 6-12 inches below water surface. K-2 sampler equipped with teflon-lined hose and glass bottles prepared for oil and grease samples.

Laboratory Procedure

The analyses performed for each type of sample are listed in Table 3 and the laboratory analytical methods are presented in Table 4.

GROUNDWATER SAMPLING

The primary purpose of the groundwater monitoring program is to characterize the shallow perched groundwater underlying and adjacent to the marsh sub-systems in order to determine the potential interactions with the wetlands. The Newark Aquifer, a major water-bearing strata in the region, occurs 20 to 30 ft below the surface and is relatively distinct from local surface water systems. In terms of interaction with the wetlands project site, the shallow groundwater table -- to a 10-ft depth -- was determined to have the greatest potential effect on wetland conditions because plant root activity would not extend beyond that depth.

The sampling program was designed to monitor seasonal fluctuations in the water table, particularly periods when the water table is at or above the ground surface, to determine groundwater quality trends by season, section and depth, and to ascertain if the groundwater cell underlying Systems B and D is separate from System C as previously suspected.

Sampling Stations

Eight wells were installed within Systems A, B, C and D (not yet constructed) as shown in Figure 6. Wells GW-2, 3, 4, 6, 7 and 8 were constructed in October 1984 and GW-1 and 9 in April 1985. Odd-numbered wells were excavated to depths of five ft and even-numbered wells to 10-ft depths. Wells were installed in each system with the following considerations:

- GW-1 and 2, paired wells were installed at the future site of System D. The location was above the level of ponded water during most of the year and in an area of representative vegetation for that section.

- GW-3 and 4 were installed at the highest point on the overland flow in System B. The wells were sited away from the edge of the system to avoid surface flows along the perimeter of the overland flow area.

- GW-6 was installed at the west end of System A, adjacent to the System C channel. Due to the presence of dredge spoils and probable leachate contamination, no corresponding 5-ft well for GW-5 was installed. GW-6 was monitored primarily for groundwater

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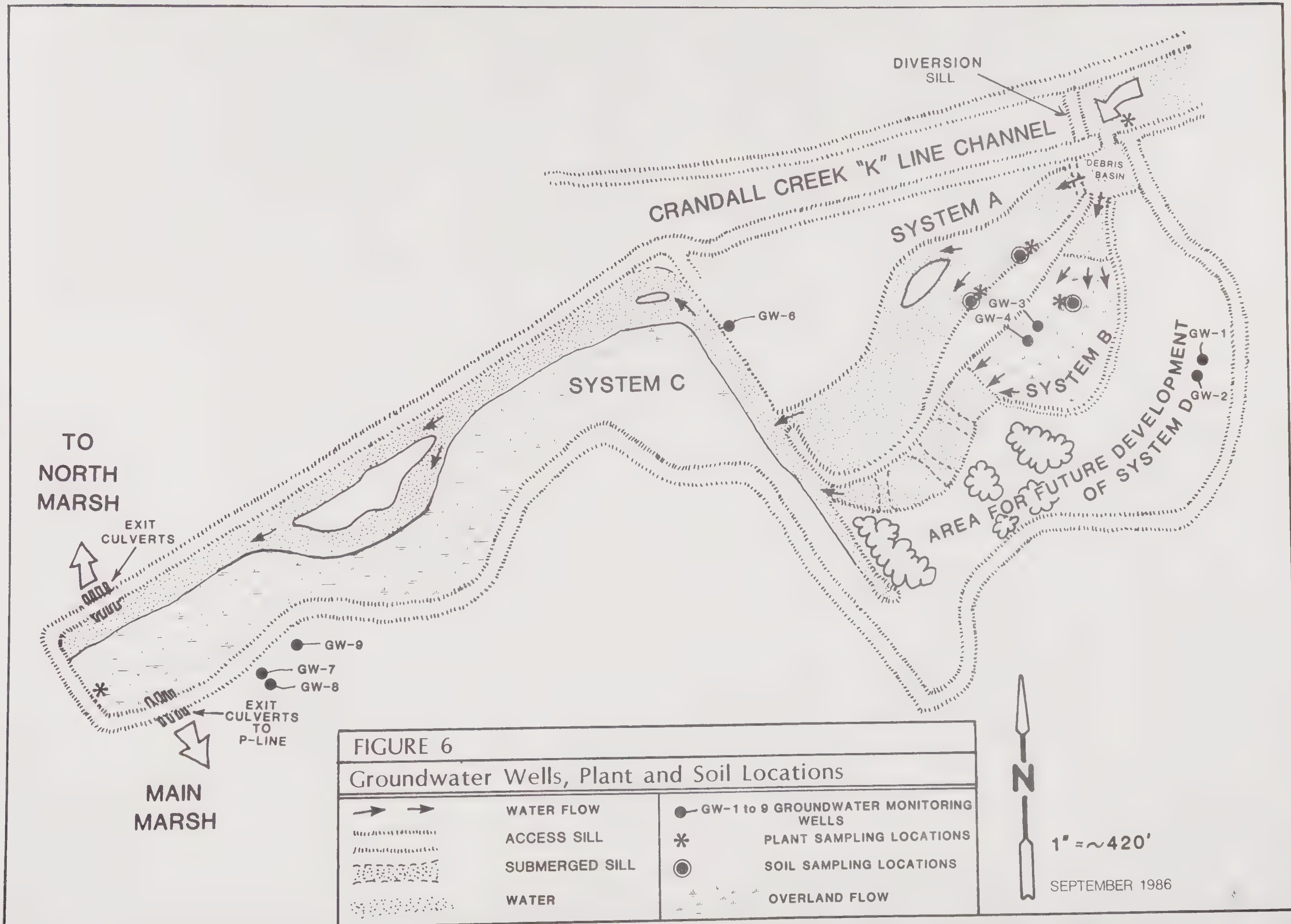


FIGURE 6

Groundwater Wells, Plant and Soil Locations

elevations and to determine whether groundwater at that site was contiguous with System C.

- GW-7 and 8 were located toward the west end of System C in an area with thick stands of alkali bulrush, which were typical of that area.

- GW-9 was sited about 50 feet east of GW-7 in a zone of pickleweed vegetation. Examination of a topographic site map indicated the presence of a wide shallow swale through that area. This feature, coupled with the observed shift toward a salt-tolerant plant species (pickleweed) suggested a change in groundwater conditions. A 5-ft observation well was installed for comparison with nearby GW-7 well.

Well Design and Installation

The design of the 5- and 10-ft sampling wells is shown in Figure 7. The Alameda County Water District and the California Department of Water Resources were consulted for the local groundwater characteristics and various methods of well construction. Of particular note is the slotted well casing on the lower 5-ft section of each well, which is sealed from infiltration along the upper portion of the well shaft by a cement seal. The depths of 5- and 10-ft were selected for the following reasons:

- 0- to 5-ft: zone of soil microbe and plant activity, as well as seasonal evaporation effects.

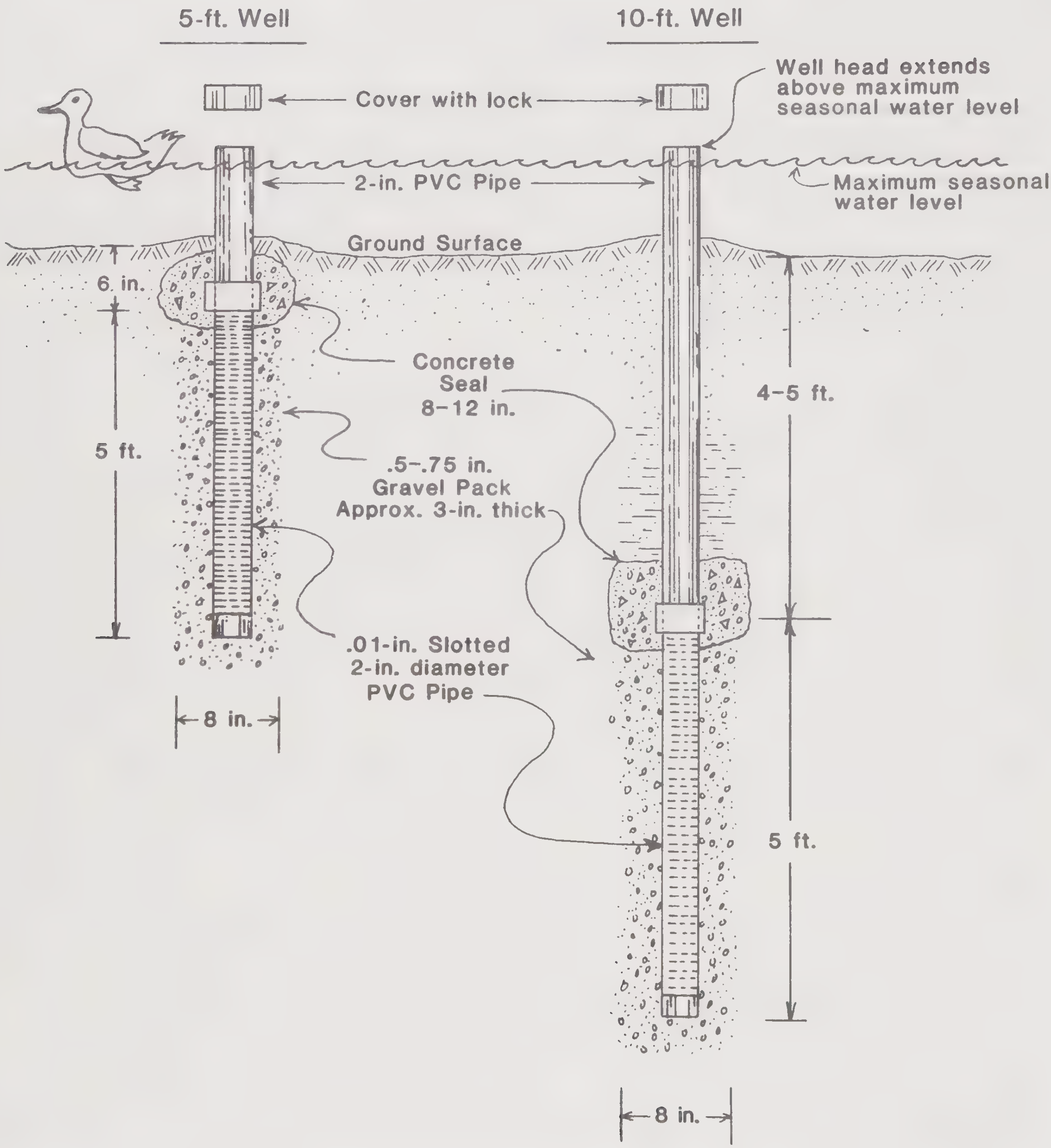
- 5- to 10-ft: zone of reduced soil microbe and plant activity. Leachates from upper layers and continuity with groundwater under adjacent systems are of concern at this level.

The well casings were not capped at the bottom except for GW-4 where water-saturated sand would have filled the bottom of the pipe. All of the well tops were capped and locks installed on GW-3, 4, 7 and 8 to minimize tampering.

Monitoring Program

All well heads were surveyed by the EBRPD survey crew to determine elevations above mean sea level. Fluctuations in groundwater levels were periodically measured by inserting a surveyor's tape into the well and subtracting the distance to groundwater from the well-head elevation. Water samples were collected with a hand pump. The well column was first evacuated and allowed to refill several minutes before collecting the sample. The samples were analyzed for pH, conductivity, TDS, chlorides, nitrate-nitrogen, Kjeldahl nitrogen, orthophosphate and total phosphorus according to the laboratory procedures listed on Table 4.

FIGURE 7 GROUNDWATER SAMPLING WELL DESIGN



DEVELOPMENT OF PLANT COMMUNITIES

Vegetation Survey

Site Selection --

The three-acre overland flow area in System B, as shown on Figure 8, was selected for the plant community development study. This area was designed to provide a water-soil-vegetation interface for physical entrapment and absorption of pollutants from surface runoff as well as biological uptake of pollutants from the soil matrix and ambient water conditions. The extent of pollutant treatment by a wetlands system can depend on the type of vegetation and its seasonal growth characteristics.

The overland flow was devoid of vegetation after the completion of marsh construction in fall 1983. Selection of this site allowed a systematic study of the developing plant communities, as well as comparisons against the developing soil conditions. The seasonal extent of vegetative growth at this site would also be used to assess the difference in stormwater runoff treatment levels between the 1984-85 and 1985-86 wet seasons.

Survey Procedure --

The Quadrat Sampling Technique (Cox, 1981), was used to obtain quantitative information about the composition and characteristics of the developing plant community. The minimum survey area (m^2) necessary for an adequate representation of the plant community was based on a species-area curve (Barbour et al, 1980). This method determines the appropriate sample size based on the vegetation community type being sampled. The survey technique is described below:

1. A 50-meter baseline was established at the north end of the overland flow area. On this baseline three perpendicular transect lines, 250 meters long, were run from randomly selected points, as shown in Figure 8.

2. For valid statistical analyses, at least 40 quadrats were required. A total of 42 random numbers were selected to determine the three transect lines. On each transect, 14 points were plotted.

3. For each quadrat, a 0.25 m^2 frame was set along the transect line at the selected random number coordinates. The 0.25 m^2 frame is a standard size for sampling herbaceous material.

4. Within each quadrant, individual plants were counted, measured and identified. Samples of each type of vegetation were also taken to the California State University Hayward Herbarium for identification and verification.

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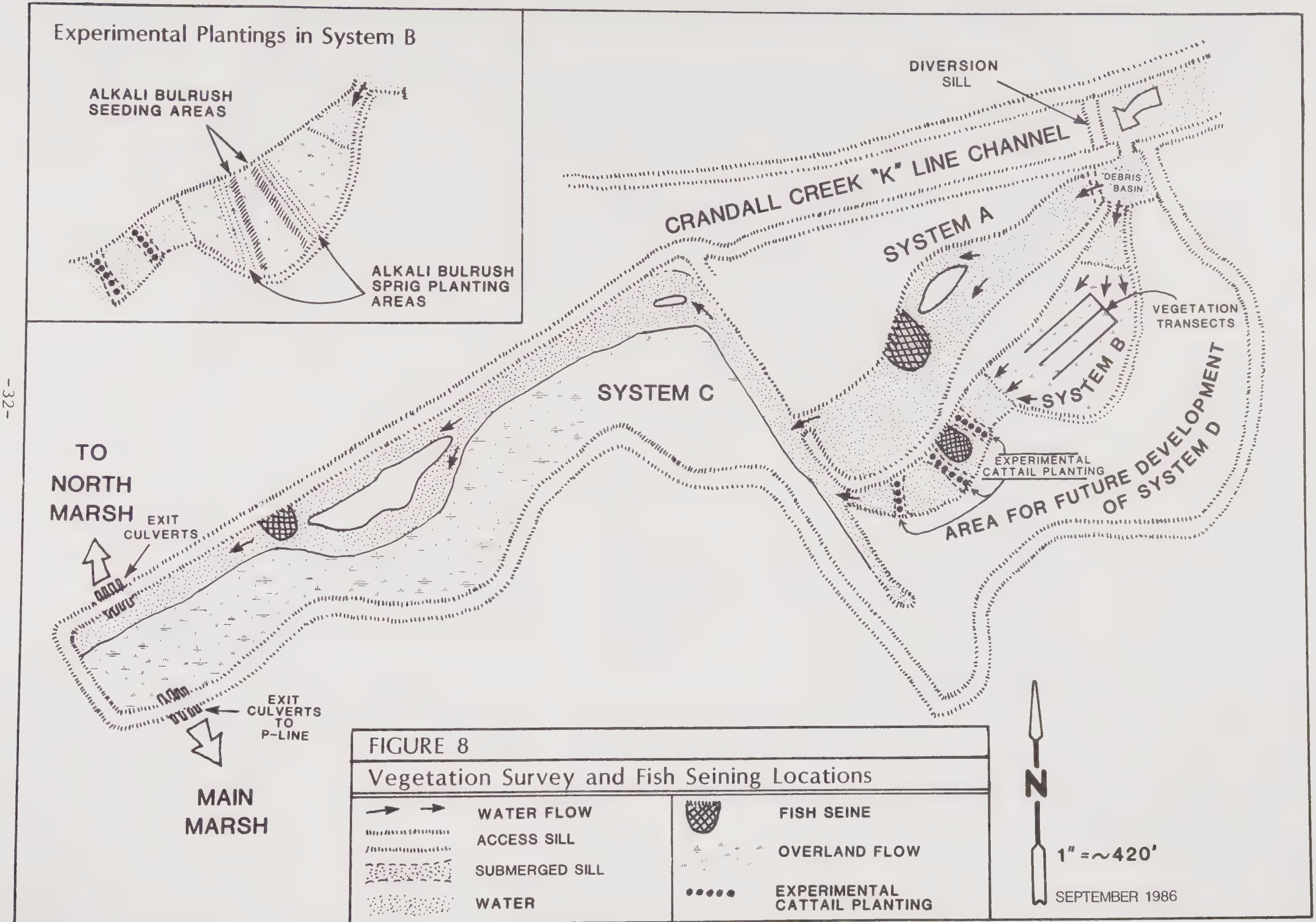


FIGURE 8

Vegetation Survey and Fish Seining Locations

5. Relative density, relative dominance, relative frequency and importance values were calculated for each species.

The initial survey to establish baseline conditions was conducted in October 1984. Due to extensive system disturbance during the experimental plantings (to be discussed in the next section), no survey was conducted in 1985. A follow-up survey was conducted in July 1986 to determine subsequent system changes.

Experimental Cattail Planting

The primary objective of the experimental planting program was to accelerate the establishment of a vegetative system that could cause water quality treatment in the DUST Marsh. The modifications were desirable in order to maximize the range of the project within the 2-year time limitation of the study. Natural succession would have taken many more years. In addition, the marsh vegetation planting techniques could provide important information for future marsh enhancement and restoration projects.

Site Selection --

The three submerged sills transecting System B (Figure 8) were chosen for the experimental planting. The sill elevations were constructed at 1 to 3 feet below the mean water level, at depths suitable for the growth of cattails. Thus, water flowing across the sills would be "combed" by the lineal cattail stands. The cattail "comb" system was designed to increase the plant-water interface as compared to pond systems where contact with emergent vegetation occurs only along the pond perimeter.

Plant Selection --

Two species of cattails, *Typha latifolia* and *T. angustifolia*, were selected for the experimental planting effort. Cattail marshes have demonstrated a potential for removal of significant quantities of water pollutants, including phosphorus (Prentki et al, 1978; Spangler et al, 1976), nitrogen (Prentki et al, 1978; Klopatek et al, 1978; Fetter et al, 1978), BOD (Fetter, 1978), and some heavy metals (Seidel, 1976). The species chosen have the following characteristics:

- Common occurrence in freshwater marshes,
- Erect, stout perennials,
- Grow well in up to three feet of water, and
- Readily available in the DUST Marsh area.

Field Planting --

Field planting was conducted on 20 October 1984 by six people. From recommendations by Dr. T. H. Harvey, an expert on local marsh ecology,

cattail plugs of 6- to 8-in. diameter were dug up from nearby stands for transplanting. Each plug consisted of one to three plants and included stem, leaf, rhizome and attached roots. The plugs were planted to a six-in. sediment depth and about three feet apart along the sills.

Average water depth along the three sills was 2 to 2-1/2 ft leaving approximately 2 to 4 ft of cattail plant exposed. The following numbers of cattail plugs were planted along each sill:

Berm No.	No. of Plugs	Species	Water Depth
1	26	Typha latifolia	1 to 2 ft
2	22	Typha latifolia	1-1/2 to 2-1/2 ft
3	12	Typha angustifolia	2 to 2-1/2 ft

Experimental Bulrush Planting

During Spring/Summer 1985, plantings of alkali bulrush sprigs and seeds were carried out on portions of the overland flow area within System B. As with the cattail plantings, the goal was to accelerate the growth of marsh vegetation in System B to provide better plant/soil treatment conditions during the winter runoff period.

Site Selection --

The broad, gradually-sloping overland flow areas within System B provided ideal conditions for alkali bulrush growth. Based on George (1963) and various communications with the Department of Fish and Game, the optimum depth of water for seeding was 0-12 inches. The overland flow area is characterized by a broad mound across the center that becomes dry during the spring through fall months. Areas adjacent to the mound maintain suitable planting depths, and 100-ft zones upstream and downstream of the dry area were selected for bulrush seeding (See Figure 8).

Plant Selection --

Alkali bulrush (Scirpus robustus) was selected for the experimental planting effort based on the following observations:

- alkali bulrush seedlings and sprigs were the most common (and apparently most successful) plants found on the overland flow area during the October 1984 vegetation survey;
- alkali bulrush plants were dominant in the adjacent K-line channel, and provided a convenient and plentiful supply for transplanting.

In addition, alkali bulrush provides useful waterfowl food and has the potential for removal of water pollutants (see references in Experimental Cattail Planting section).

Field Planting --

Bulrush plantings were conducted during May and June 1985 by six people. Alkali bulrush sprigs with new growth and no flower stalks were dug up from the K-line channel and transported to the overland flow area. Using a rope guideline system, approximately 250 sprigs were planted 5-ft on center in 5 rows in the designated upstream zone and a corresponding 250 sprigs were planted in the downstream zone (500 plants total).

Fifty pounds of alkali bulrush seed were presoaked for 3 days in a 1 percent chlorine solution to deter bacterial growth and promote germination. During the first week of May, seeds were hand sown and the mud subsequently raked to improve seating and to conceal the seeds from waterfowl predation. The seeding rate was approximately 20-30 lbs/acre. This was intentionally high to compensate for the high seed dormancy rate (George, 1963).

SOIL AND SEDIMENT SAMPLING

The sampling program was designed to establish vertical trends in soil and sediment chemistry. Additionally, the influence of vegetative cover and location within the DUST Marsh was investigated.

Methods and Sampling Situations

Soil samples were collected in November 1984 and July, September and November 1985. Sampling locations are shown on Figure 6. The sampling station locations coordinated with the heavy metals vegetation sampling. At locations where the ground was firm and dry, a large hole at least 2-ft deep and 2-ft wide was dug by shovel to expose the various soil strata. The holes were examined visually to determine the extent to each soil horizon and samples were taken with plastic and wooden scoops from the surface layer (0 - 4 in.), A-1 horizon (4 - 8 in.), and the A-2 horizon (8 in. +). The surface layer included the soft unconsolidated material making up the "O" horizon. The middle and lower layers were subparts of the "A horizon" where soils were more uniform and consolidated. The middle layer contained roots and inclusions, whereas the lower layer was beyond the plant root zone. The widths of each stratum varied slightly at each locations. Where the ground was soft and/or under water, a hand core-sampling device was used. For the softer sediments, a modified split-spoon sampler was constructed from 2-in pvc pipe. For the firmer sediments, a 2-in. brass cover with a lexan liner and nosepiece was driven into the ground with a 5-lb slide hammer assembly. For each core sample, the percentage of compaction was calculated and subsamples were divided according to the previously determined depth divisions.

Within each system, soil samples were obtained where alkali bulrush (*Scirpus robustus*) and cattail (*Typha latifolia*) were dominant. No

cattails were found on the overland flow section of System B in October 1984. Additionally, in 1985 only, soil samples were collected in the K-Line Channel at Newark Blvd (Station K-1) and adjacent to the Debris Basin (Station K-2) among dense vegetation stands. At each soil sampling site, the extent and characteristics of each soil stratum were noted and included observations on soil texture, consistency, color and presence of roots and other materials. All samples were stored in sealed plastic bags with appropriate identification.

Laboratory Procedures

Soil samples were returned to the laboratory, air dried, crushed, homogenized and screened through a 2-mm diameter sieve. Analytical procedures are summarized in Table 4.

HEAVY METALS SAMPLING -- VEGETATION

The fate of urban runoff pollutants into the wetland environment was monitored through selected plant species to determine bioaccumulation above background concentrations.

Plant Species Selection

Two plant species were collected for heavy metals analyses based on their general abundance and wide distribution throughout the marsh. The species chosen as representative of vegetation within the new marsh were:

- *Typha lactifolia* (broadleaf cattail) -- the most common marsh species at Coyote Hills Park growing in fresh to brackish waters and tolerating prolonged inundation;

- *Scirpus robustus* (alkali bulrush) -- another common marsh species tolerating brackish water and providing important wildlife food value.

Site Selection

The focus of plant and soil studies was on System A and B where the marsh environment was newly developed. Soil and vegetation samples from these areas were more likely to contain recently-accumulated water pollutant constituents from the previous storm season. Whereas System C was well-established and recent accumulation effects would be more difficult to differentiate from long-term effects. Two cattail and two bulrush sampling stations (one each in Systems A and B) were planned for monitoring in 1984. Under actual field conditions, no cattail was found in System B in 1984. The monitored sites are shown on Figure 6. In 1985, two additional stations were sampled: K-2 and C-2. Biomass measurements were also conducted at these stations.

Field Sampling

The field sampling schedule is shown in Table 6. At each alkali bulrush site, plant material from 10 to 15 plants within a 9 m^2 area was collected and excess soil removed from the roots. Each plant was separated into three parts and pooled into collective samples of: (1) fruit/seed, (2) stem/leaf, and (3) root/rhizome. At the cattail sites, 5 to 10 cattail plants were collected and similarly composited into sub-samples of the various plant parts.

At the stations where biomass was measured, random 1-m^2 quadrats were staked out in relatively pure stands of cattail or bulrush. All vegetation within the 1-m^2 area was removed, cleaned and separated into root/rhizome, leaf/stem and seed parts. The fresh weight of the three component plant parts was taken. Due to the multiple stem growth habit and dense intertwined vegetation, counts of individual plants per quadrat were not taken. Due to the large volume of plant material collected (up to 44 kg in one sample), aliquots were taken by spreading out the chopped and mixed plant parts onto a clean ground surface marked with gridlines and selecting one or more grids at random to achieve 25 percent of the total sample. The aliquots of 15 to 25 percent were weighed, dried in an oven at 103 degrees Fahrenheit for 24 hours and reweighed to determine the equivalent dry weight.

Laboratory Methods

Leaf samples were washed in a mild soap solution, rinsed and dried. Root and rhizome samples were scrubbed to remove excess dirt, rinsed and dried. Plant tissue samples were oven-dried at 55 degrees Celsius, crushed, homogenized and subsequently ashed. The analytical procedures follow the methods presented in Table 4.

TABLE 6. SOIL AND PLANT SAMPLING SCHEDULE

Location	1984	1985
Station K-2 in K-line channel near Debris Basin inflow	No samples taken	Cattail, bulrush, biomass and soils July - Sept. 1985
System A, south bank	Cattail and soils only Oct. 1984	Cattail, bulrush and soils Oct. - Nov. 1985
System B, overland flow area	Cattail, bulrush and soils Oct. 1984	Cattail, bulrush and soils Oct. - Nov. 1985
Station C-2, in System C at west end near Main Marsh	No samples taken	Cattail, bulrush, biomass and soils July - Sept. 1985

HEAVY METALS SAMPLING-FISH

Heavy metals generally occur at very low concentrations in the water and increase in sediment and plant tissues through various interactions and uptake mechanisms. Animal species on secondary and tertiary trophic levels have the potential to bioaccumulate heavy metals beyond the surrounding environmental levels. The analysis of fish tissues as an indicator for bioaccumulation was included in the workplan at the suggestion of Mike Rugg from the California Department of Fish and Game. Fish are generally abundant throughout the study area, easy to collect, and the results may be useful for comparisons in other areas.

Fish Species Selection

Initially, the mosquito fish (*Gambusia affinis*) was selected as a single indicator species for assessing bioaccumulation in the DUST Marsh. After a field examination, other species were included in consideration of their abundance, seasonal population fluctuations, feeding habits and position within the food chain. The species selected for study were:

- *Gambusia affinis* (mosquitofish) The mosquitofish is stocked by the Alameda County Mosquito Abatement District for mosquito control. The average size caught in the DUST Marsh is about 3.6 cm total length. Gambusia feed on insect larvae at the water surface and also serve as a food source for larger fish and birds. The mosquitofish are not abundant enough throughout the year to warrant use as a single indicator species.

- *Gasterosteus acculeatus* (threespine stickleback) Averages about 4.5 cm total length and is also a food source for larger fish and birds. The stickleback diet consists of algae and small aquatic organisms, primarily insects and crustaceans from the bottom and in the water column of the marsh. Stickleback populations, like mosquitofish, also vary widely during each season and are not always available for collection in significant numbers.

- *Cottus sp* (sculpin) Sculpins are primarily a bottom dwelling fish and edaceous eaters. Included in their diet are: fish eggs, small sculpins, and small fish from the water column (such as mosquitofish and sticklebacks). Average size caught in the DUST Marsh is about 7 cm total length. With specialized collection techniques, sculpins may be captured in sufficient numbers for analysis during all seasons.

- *Orthodon microlepidotus* (Sacramento blackfish) The blackfish feeds on bottom detritus and plankton filtered from the water column and is consumed by humans. The largest size collected in the DUST Marsh for analysis was about 32 cm total length. Blackfish are available in abundant numbers year around for collection and analysis.

- *Cyprinus carpio* (carp) Carp are bottom "rooters" that feed on animal matter, plant material and mud. They are also consumed by humans. The largest size collected from the DUST Marsh for analysis was about 50 cm total length. Carp are available most of the year for collection and analysis.

Site Selection

Two locations were chosen for the 1984 seining effort: one in System A and one in System C (Figure 8). In 1985 an additional site in System B was included. Factors in site selection included accessibility for sampling equipment, areas of high fish activity and areas representative of the beginning and ending portions of the DUST Marsh system.

The System A and B sites are in a recently constructed portion of the DUST Marsh where soil and plant community development are in early successional stages. The System C site is in an established marsh channel with well-developed bank vegetation of bulrush, cattails and willows. Since the marsh was two years old, it was anticipated that the smallest fish -- gambusia and stickleback -- would have passed a major part of their life cycle within one system.

Field Sampling

Fish seines were conducted in October 1984 and April, June and October 1985. The initial focus was an analyses of gambusia, and in the October 1984 seine only that species was preserved for analysis. In subsequent surveys multiple fish species were collected. A 3/8-in. seine net, 50-ft long by 4-ft high was deployed from a rowboat in a large area approximately 50 ft

from and parallel to the shore. The two ends of the seine were then hauled to shore by hand. Fish were collected, identified, counted and representative specimens taken. The largest of the blackfish and carp were kept. The remaining fish were released. Specimens were measured, counted, weighed and fresh frozen for later heavy metal analyses, except for the October 1985 survey where blackfish and carp were dissected fresh. At the time of preparation, fish were again weighed, measured and grouped according to species and sample location. Each group was dissected open on plastic trays with clean paper liners. All tools were washed in detergent and tap water, rinsed with dilute nitric acid, rinsed with deionized water and then dried before use. The thawed fish were dissected along the ventral surface with a stainless steel scalpel, forceps and scissors. In carp specimens, the gut and attached liver were excised and laid out straight and the liver gently pulled away from the connective tissue. Livers were composited into plastic bags and frozen until just prior to analysis. Half of the samples were taken to the California Fish and Wildlife Water Pollution Control Laboratory and the remainder were taken to a contract laboratory.

Fish traps were also set out in July and November 1985 to supplement the low number of gambusia and sticklebacks caught in the June and October seines. Inverted funnel traps with fine mesh lining were set at surface, middle and bottom depths for 24 hours. Fish were collected, identified, weighed, measured and fresh frozen for later heavy metal analyses.

A supplemental fish seine was conducted in October 1986 to measure flesh concentrations, verify the heavy metal concentrations found in blackfish and carp livers, and develop a flesh-to-liver concentration ratio for these species. The sampling, preservation and analysis techniques were similar to the previous surveys except that fish were analyzed for cadmium, chromium, copper, lead, zinc and selenium.

Laboratory Procedures

Fish tissue analysis followed the methods in the Toxic Substance Study (California Department of Fish and Game, 1985) and is summarized below. Prior to analysis, each composite fish sample was diluted (1:1) with Milli-Q reagent grade water and homogenized to a paste-like consistency in an all glass sample container using a Brinkman Polytron homogenizer with a titanium cutting assembly. Composite liver samples were homogenized using the Polytron homogenizer and titanium cutting assembly. The samples were then refrigerated or frozen in all-glass bottles until analyzed. Liver and fish composites were analyzed for seven trace metals.

Digestion techniques and instrumentation for the detection of trace metals in tissues are presented, with the detection limits, in Table 7. Techniques employing conventional (flame) atomic absorption spectrophotometry were done on a Varian Model AA-475 atomic absorption spectrophotometer. Procedures requiring a graphite furnace were done on a Perkin-Elmer Model 5000 atomic absorption spectrophotometer equipped with a HGA-500 graphite furnace. All analytical values were corrected using procedural blanks.

TABLE 7. DIGESTION TECHNIQUES, INSTRUMENTATION, AND DETECTION LIMITS FOR TRACE METAL ANALYSES IN TISSUE

Element	Digestion Techniques	Instrumental Analysis	Tissue Detection Limits (ug/gm fresh weight)
Cadmium[1]	HNO3 wet pressure	Graphite Furnace	0.01
Chromium[1]	HNO3 wet pressure	Graphite Furnace	0.02
Copper[1,2]	HNO3 wet pressure	Flame A.A.	0.02
Lead[1]	HNO3 wet pressure	Graphite Furnace	0.1
Manganese[1]	HNO3 wet pressure	Flame A.A.	0.05
Nickel[1]	HNO3 wet pressure	Graphite Furnace	0.1
Zinc[1]	HNO3 wet pressure	Flame A.A.	0.05
Selenium [3,4]	HNO3 wet pressure	Graphite Furnace	0.2

References:

(1) Adrain, W.J. 1971.
(2) Leonard, C. M. 1971.
(3) Agemian, H. 1980.
(4) EPA, 1984.

SECTION 3
HYDROLOGY

ESTIMATION OF RUNOFF

The DUST Marsh receives runoff from the Crandall Creek/K-Line drainage area, as shown in Figure 9. Rainfall data for Winter 1984-85 were obtained for the ACFCD Decoto rain gauge from the Union City Fire Department. The Decoto gauge, located 0.5 miles north of the watershed, was the nearest regularly-monitored gauge and was considered representative of the watershed conditions. Storm data were recorded as total precipitation within a 24-hour period. Supplemental rainfall data for selected storms were also gathered at the Coyote Hills Park Visitor's Center. For the winter 1985-86 season, the Alameda County Water District (ACWD) #1940 gauge -- located 0.7 miles east of the watershed area -- at the ACWD Water Softening Plant on 1111 Mowry Avenue in Fremont was used. Rainfall was monitored on a tipping-bucket rain gauge recorder that provided useful information on time of first rain, storm duration and rainfall intensity as well as total precipitation.

The Crandall Creek watershed was divided into 14 drainage sub-units for the determination of stormwater runoff. The drainage area characteristics are presented in Table 8. Based on storm runoff calculations by the Alameda County Flood Control District (ACFCD), estimates of peak storm flow and total runoff volume can be obtained for a given storm based on rainfall amount, as shown in Figure 10. As part of the Flood Control Master Plan for the Fremont area, Coyote Hills Park (including the area later developed into the DUST Marsh) was set aside as the Crandall Creek floodwater retention area for the 100-year intensity storm (approximately 3.5 inches falling within 6 hours). The Flood District performed extensive channel modifications on Crandall Creek, which they designated the "K-Line" and levee and drainage improvements on the Coyote Hills Park flood basin.

In addition to the Crandall Creek watershed area, approximately 200 acres of agricultural land drains directly into the DUST Marsh, as shown in Figure 9. Agricultural runoff collects in a wide drainage channel within the area and is pumped directly into the DUST Marsh Debris Basin after large storms. The 55-acre DUST Marsh Basin accounted for less than 2 percent of the Crandall Creek drainage area and 5 percent of the total runoff, and was considered a minor factor in calculating runoff volumes.

The estimated runoff volumes and peak storm flows for the Winter 1984-85 and 1985-86 monitored storms (based on the formulas in Figure 10) are shown in Table 9. The equations represent a 6-hour storm under "average season conditions." Under actual conditions, runoff volumes would be reduced when there were long dry periods before storms and increased when the ground becomes saturated by prolonged rains. The data in the table provide an estimate of storm runoff and flow magnitude. Field measurements would, however, more closely reflect the actual watershed conditions.

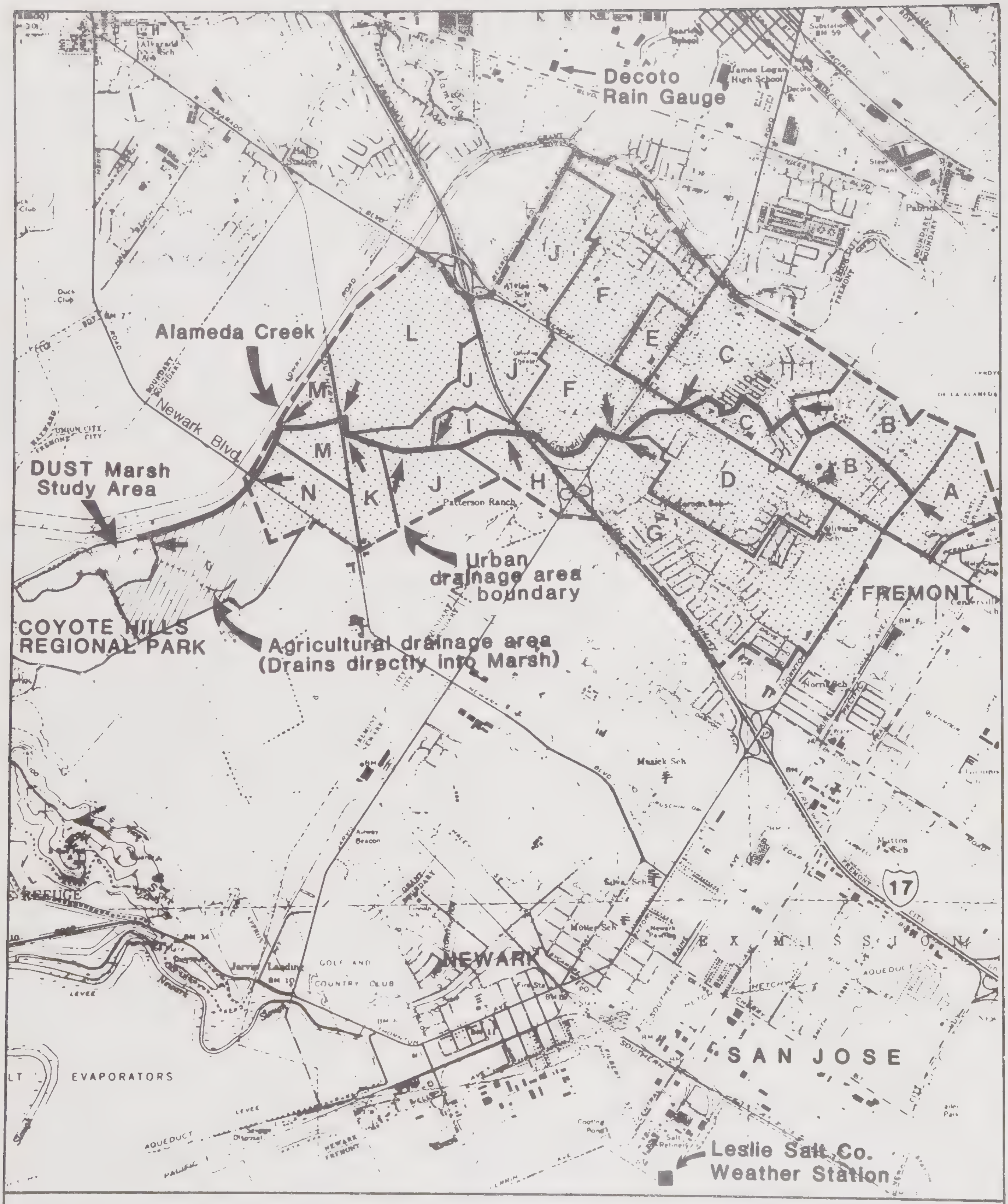


Figure 9 CRANDALL CREEK / K-LINE DRAINAGE AREA

LEGEND

A-N Drainage sub units

Crandall Creek K-Line Channel

Points of Drainage Concentration

SCALE
1in.=3500 ft.

Map Source: USGS

TABLE 8. CRANDALL CREEK, K-LINE WATERSHED CHARACTERISTICS*

Drainage Area	Area (acres)	Runoff Coefficient
Crandall Creek		
A	103.3	0.5
B	238.8	0.4
C	274.0	0.4
D	252.5	0.4
E	52.1	0.4
F	420.6	0.4
G	438.9	0.4
H	58.1	0.4
I	17.7	0.4
J	376.7	0.4
K	54.4	0.4
L	268.1	0.4
M	71.4	0.4
N	78.1	0.4
Subtotal	2,704.7	-
DUST Marsh		
Agricultural area	200	0.4
DUST Marsh basin	55	1.0
Subtotal	255	-
Total Drainage Area	2,959.7	-

* Urban drainage area, based on Alameda County Flood Control District data

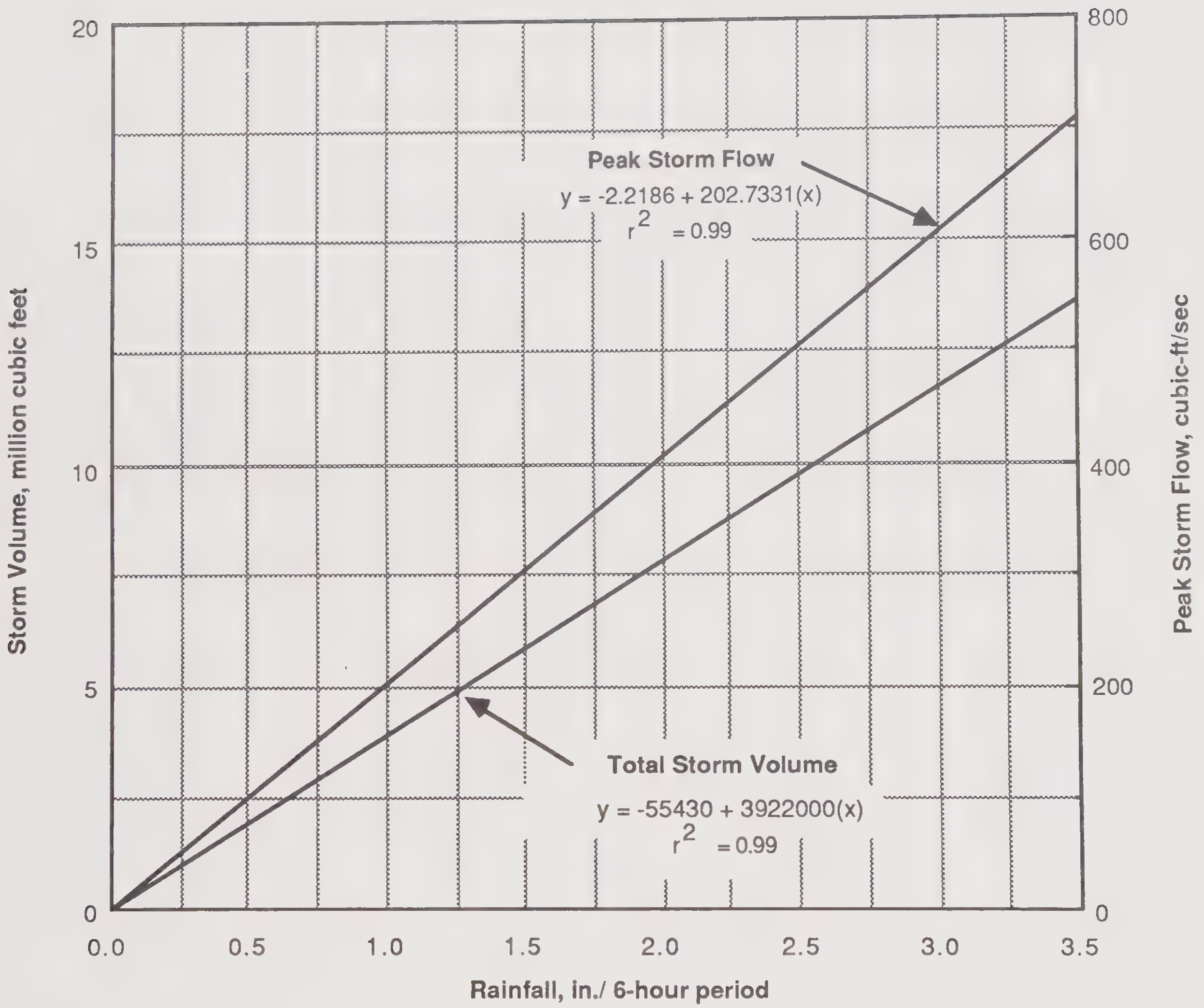


Figure 10. STORM VOLUME AND PEAK FLOW

TABLE 9. 1984-86 ESTIMATED RUNOFF VOLUMES AND PEAK FLOWS

Date	Rainfall (in.)	Duration (hrs)	Runoff Volume* (10^6 ft^3)	Peak Flow (ft^3/s)
Winter 1984-85				
13 Nov 84	1.53	12.0	5.95	307
27 Nov 84	0.80	9.0	3.36	174
8 Feb 85	1.38	10.0	5.36	276
5 Mar 85	0.80	17.0	3.08	160
Winter 1985-86				
24 Nov 85	1.14	19.4	4.42	228
3 Jan 86	0.63	38.0	2.42	126
29 Jan 86	0.35	12.0	1.32	69
31 Jan 86	0.55	3.0	2.10	109
12 Feb 86	0.59	10.0	2.26	117
14 Feb 86	1.77	2.7	6.89	357
7 Mar 86	1.06	2.8	4.10	213

Storm Hydrographs

Based on stormwater flow monitoring data, hydrographs were developed for each monitored storm and are presented in Figure 11. Accompanying rainfall intensity charts are also presented for each storm for the comparison of time-of-first-rain to time-of-peak-inflow into the DUST Marsh.

For the four storms monitored during Winter 1984-85, flow measurements at Stations A-2 and B-2 were poor and unreliable. With the installation of the flow concentration structures at these stations and more frequent monitoring during Winter 1985-86, hydrographs for Stations A-2 and B-2 could be developed. These hydrograph shapes and occurrences in relation to the Station K-2 hydrograph were examined carefully. The Winter 1984-85 hydrographs were revised to include A-2 and B-2 flows in similar configuration to the Winter 1985-86 data, but were scaled to reflect the influent Station K-2 flows for each particular storm.

Adjustment of A-2, B-2 and C-2 Flows --

Based on the hydrographs generated for each storm, total volumes of water passing through each system were calculated. The normal storm monitoring period was 50-60 hours. By that time, the K-2 (A-1 + B-1) flows generally would return to pre-storm levels. Due to the limitations of the outlet pipes at Station C-2, however, water would remain within the A, B and C Systems and discharge over the next 24-72 hours -- depending on the amount of stored water. Thus, in the Figure 11 hydrographs, the volumes at T0 [Time(hrs)] of Stations A-2 + B-2 and C-2 are generally less than the K-2 inflow volumes.

To balance the influent and effluent volumes, T0 and T50 water elevations were measured at each station. The corresponding T50 residual water (T50 volume minus T0 volume) within each system was calculated and added to each system flow. With this method, the K-2 inflows and C-2 outflows agreed within 10 percent. However, the cumulative A-2 + B-2 flows were typically less than the C-2 total flows. This indicated that either the flow measurements at Stations A-2 and B-2 were inaccurate or that water was penetrating through the flow concentration structures at these Stations and bypassing the flow measurement gate. As described previously, these structures consisted of wire mesh fences lined with overlapping fastened sheets of corrugated fiberglass.[1] Water pressure during high flows could force gaps between fiberglass sheets or perhaps induce water passage under the fence.

Figure 11. Storm Hydrographs

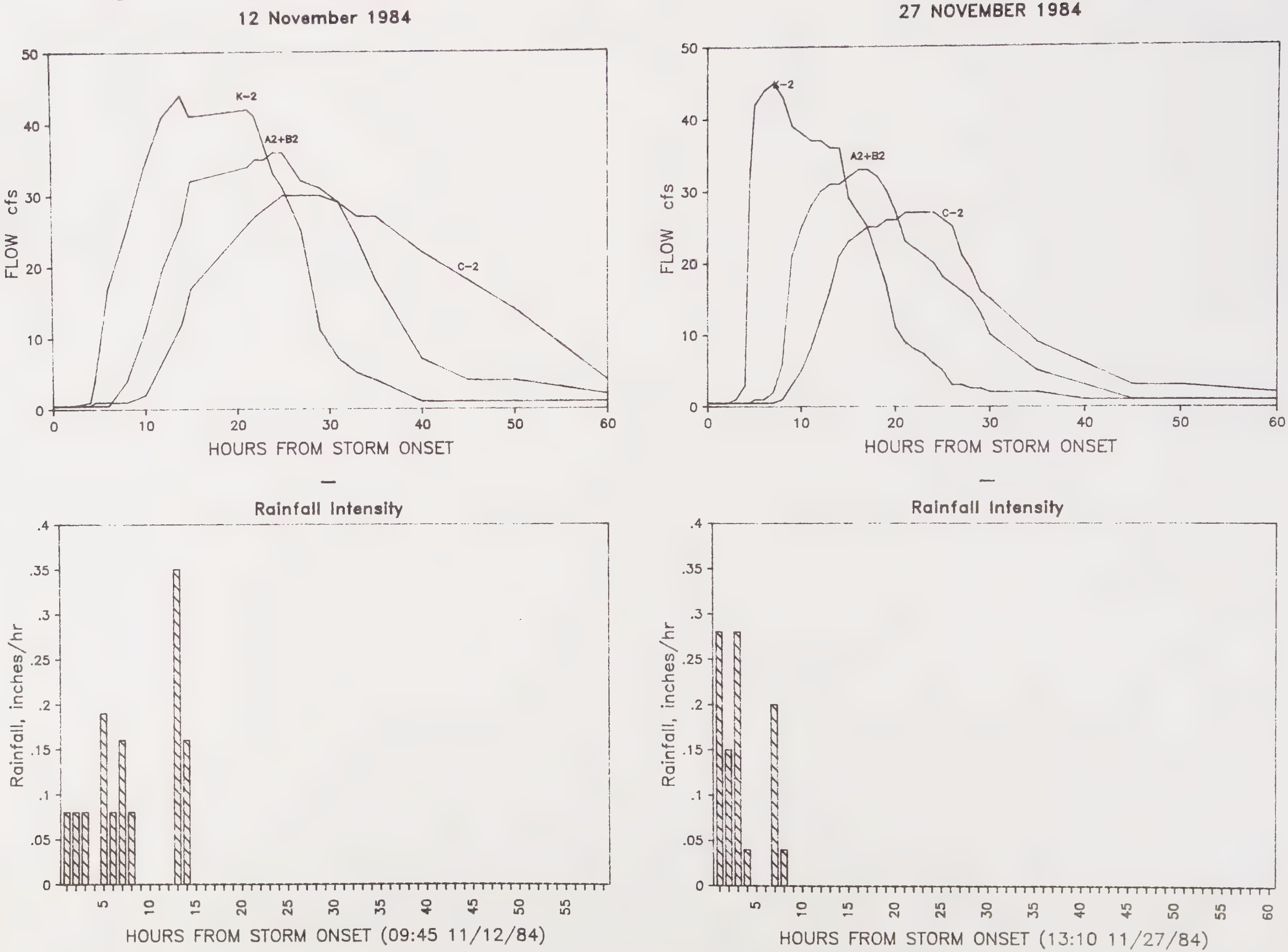


Figure 11. Storm Hydrographs, cont.

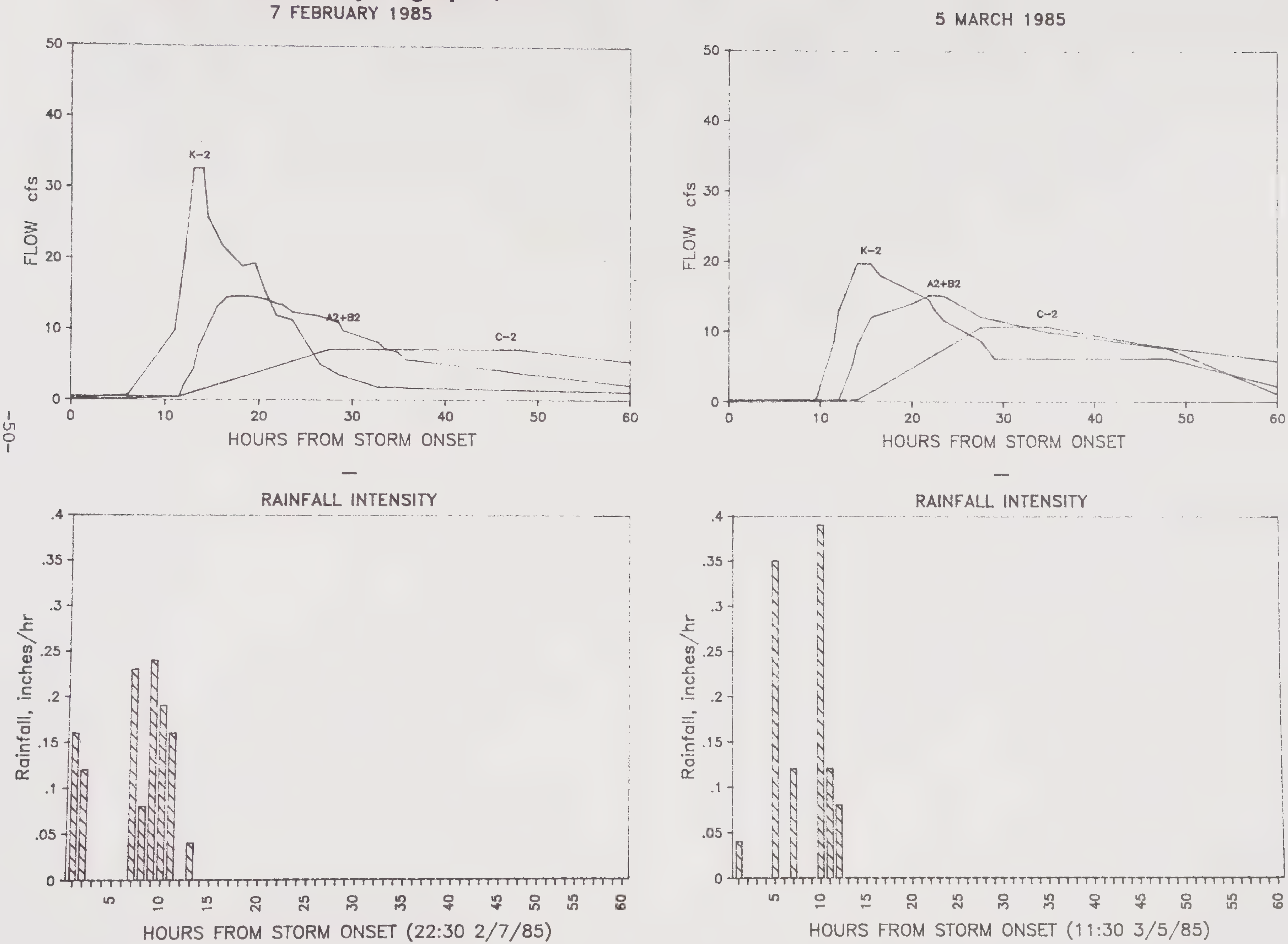


Figure 11. Storm Hydrographs, cont.

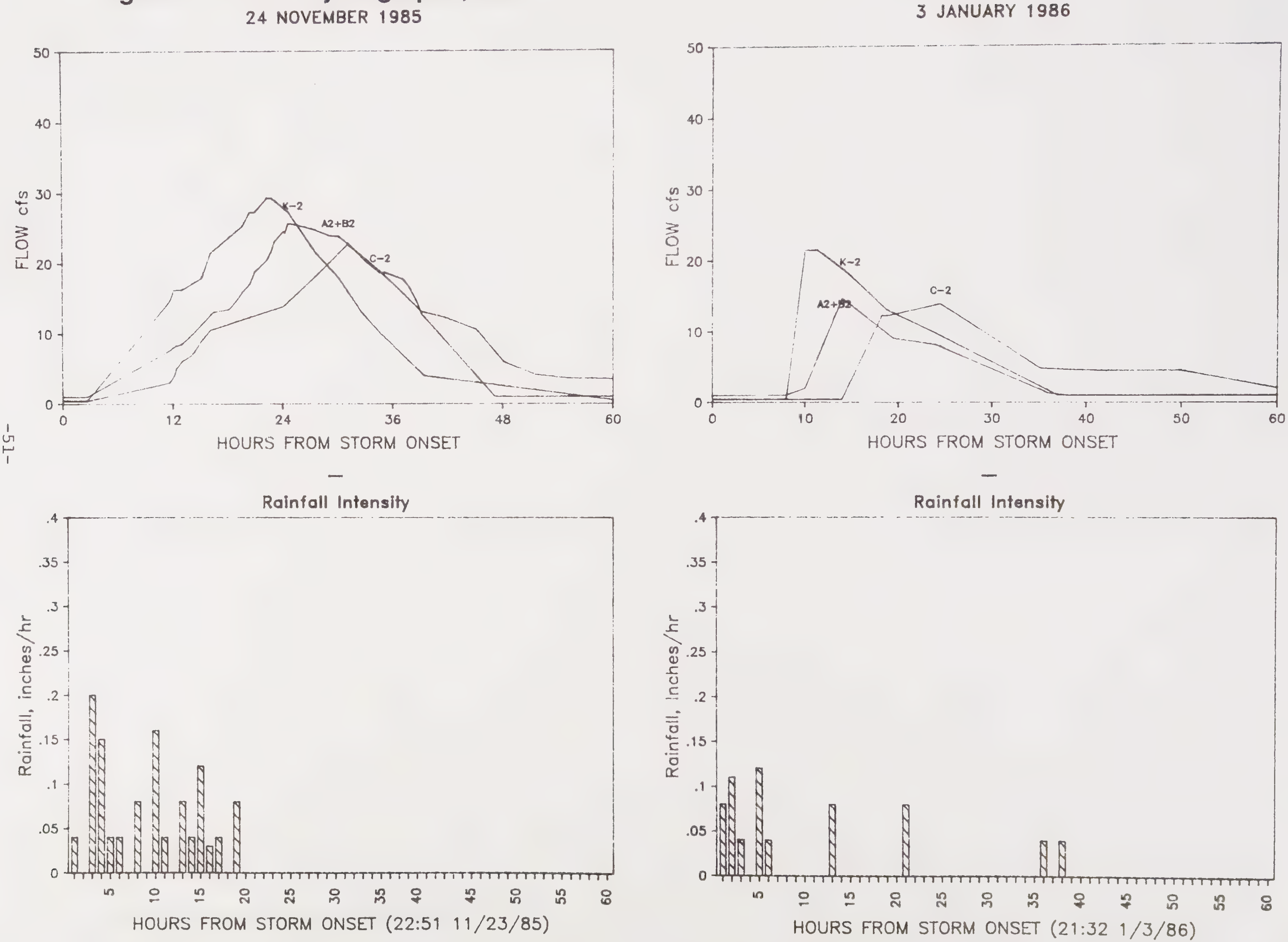


Figure 11. Storm Hydrographs, cont.

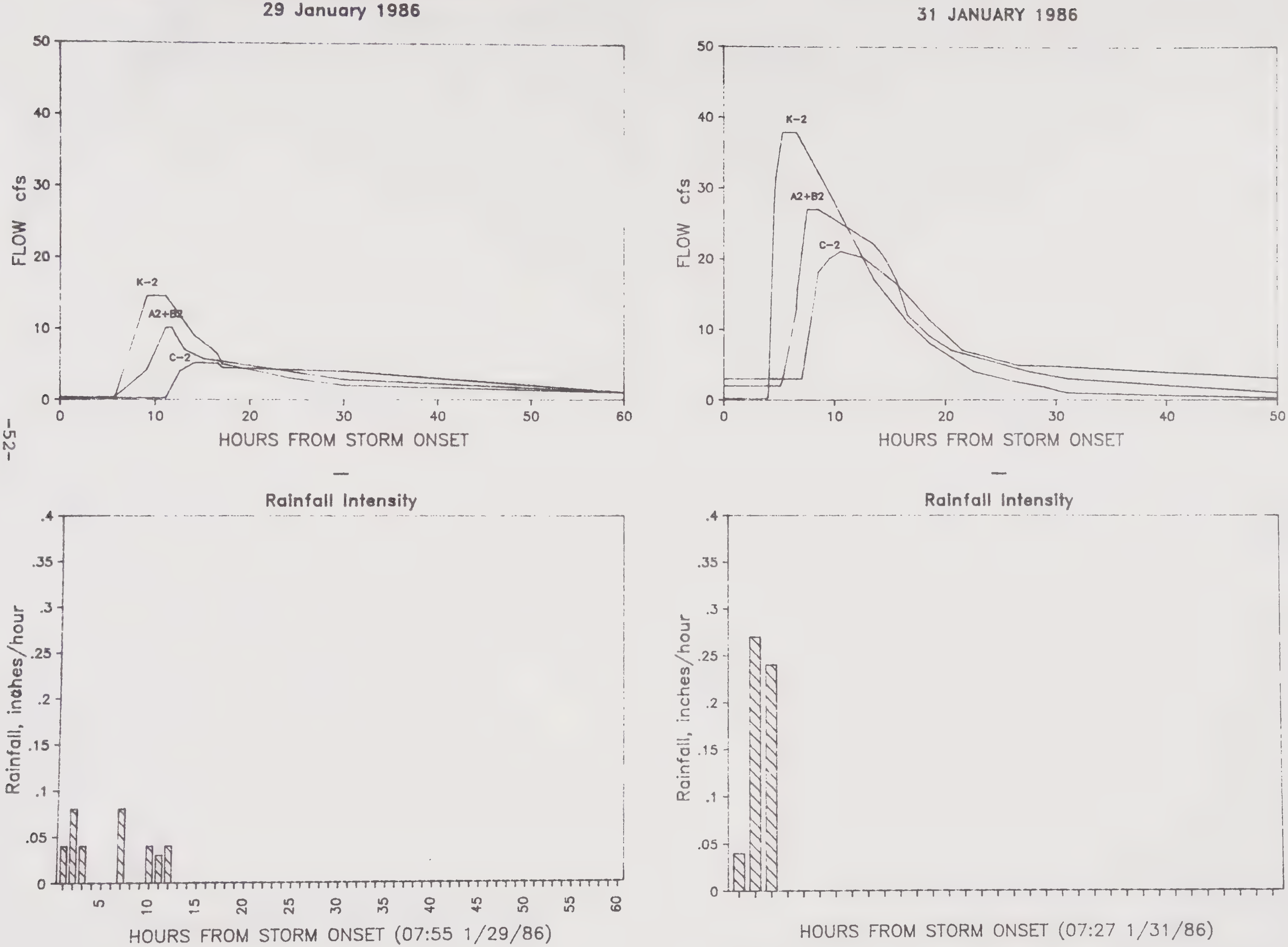


Figure 11. Storm Hydrographs, cont.

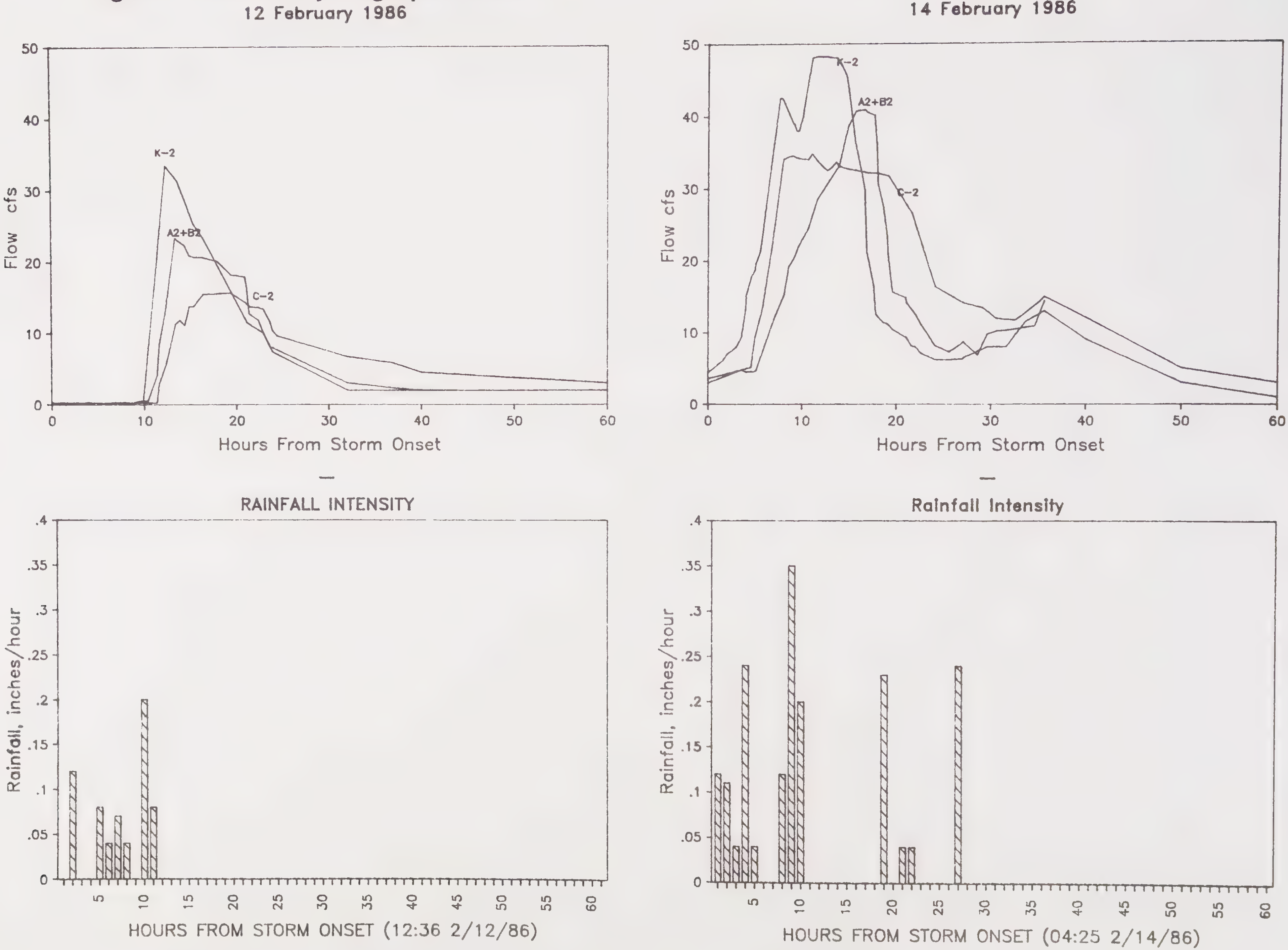
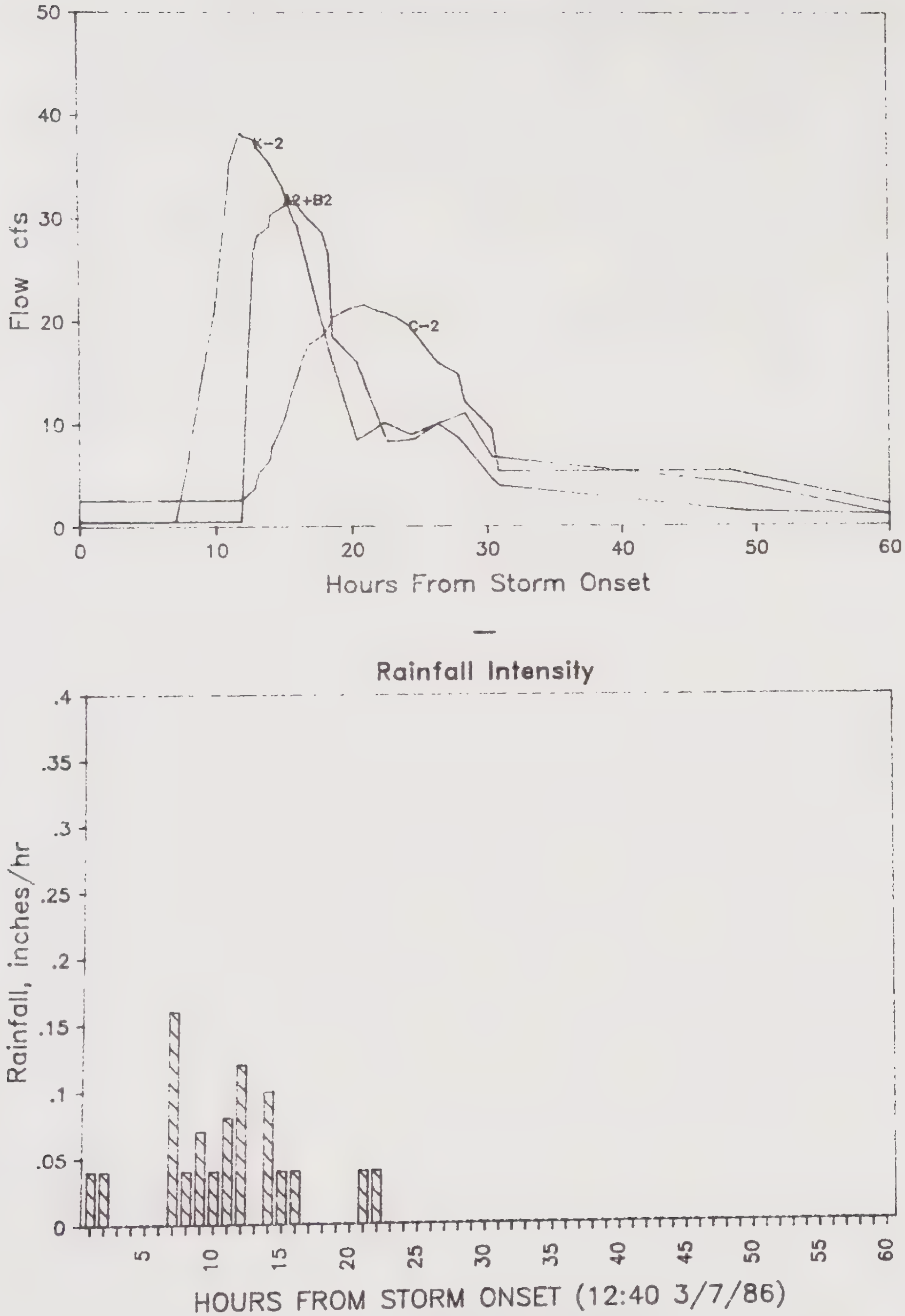


Figure 11. Storm Hydrographs, cont.

7 MARCH 1986



To determine the source of error, the 3 Feb 86 storm was monitored intensely with replicate flow meter readings at Stations A-2 and B-2 to ensure reliability of flow measurements. The results are presented below in Table 10.

TABLE 10. VOLUME CALCULATIONS FOR 3 FEB 86 STORM

Parameter	Station K-2	Stations A-2 + B-2	Station C-2
Flow T50 (10^6 ft^3)	1.58	0.98	1.30
Residual Storage at T50(10^6 ft^3)	-	0.14	0.28
Total Storm Flow (10^6 ft^3)	1.58	1.11	1.58
Ratio: $\frac{\text{C-2 volume}}{\text{A-2 + B-2 volume}}$	-	-	1.41

From this table, the cumulative A-2 + B-2 total volumes are less than the C-2 volumes. The ratio of volumes between the systems indicates that over 40 percent of the flows are penetrating through the fences. To adjust for this effect, a "fence porosity factor" of 1.41, based on the volume ratios calculated above, was applied to all A-2 and B-2 flow measurements for Winter 1985-86 monitored storms.

Observed Runoff Volumes and Peak Flows --

Based on the water level-flow correlations developed, the cumulative runoff volumes and observed peak flows for the monitored storms are presented in Table 11. From this table, the observed runoff volumes from the first two storms are significantly less than the estimated runoff volumes. As detailed in Table 2, major problems were encountered with the diversion berm on the K-Line channel at Newark Blvd. During the 13 Nov 84 storm, the earthen berm was breached and eroded away during the peak discharge period. This breach caused 80 percent of the total stormwater flows and nearly all of the peak flows to be diverted out the floodgate. Similar problems were encountered in the 27 Nov 84 storm when a section of the sandbag berm washed out during the critical peak flow period causing 86 percent of the flow to be lost. The hydrographs of these storms were, thus, reduced in magnitude and the pollutant loadings were probably also reduced.

TABLE 11. ESTIMATED VS OBSERVED RUNOFF VOLUMES AND PEAK FLOWS

Date	Estimated Volume* (10^6 ft^3)	Observed Volume (10^6 ft^3)	% Runoff Entering Marsh	Estimated Peak Flow* (ft^3/s)	Observed Peak Flow (ft^3/s)
13 Nov 84	5.95	1.20	20	307	13
27 Nov 84	3.36	0.48	14	174	8
8 Feb 85	5.36	1.39	26	276	33
5 Mar 85	3.08	1.30	37	160	30
24 Nov 85	4.42	2.29	52	228	29
3 Jan 86	2.42	1.16	47	126	22
29 Jan 86	1.32	0.56	42	69	15
31 Jan 86	2.10	1.41	54	109	38
12 Feb 86	2.26	1.17	52	117	34
+4 Feb 86	6.89	2.47	36	357	43
7 Mar 86	4.10	1.33	32	213	34

* From Table 9

In subsequent storms, the diversion berm was repaired and operated as designed. During the 8 Feb 85 and 5 Mar 85 storms, 26 and 37 percent of the total stormwater runoff entered the DUST Marsh system with peak observed flows of 30 and 33 cfs. The loss of 74 and 63 percent of the flows can probably be attributed to the peaking phenomenon associated with each storm. The peak discharge during the 8 Feb 85 storm was rapid and high causing a significant amount of water to escape over the flood gate diversion berm. The peak discharge during the 5 Mar 85 storm was less intense and more water was retained in the channel.

For storms monitored during the Winter 1985-86 season, from 32 to 54 percent of the stormflows collected in the Crandall Creek/K-Line drainage entered the DUST Marsh. For small-to-moderate storms (<0.60 in. rainfall) with estimated peak flows of less than 150 ft^3/s, peak flow measured at Station K-2 was one-third of estimated peak flow allowing for overflows at the Newark Blvd. diversion berm. For the larger storms, K-2 flows corresponded to 15 to 20 percent of the estimated peak flows. The larger storms typically occurred when the receiving marsh water levels were elevated from previous storm runoff -- causing the K-Line flows to back up the channel upstream of the marsh.

In the comparison of system design capacity and observed flows, the DUST Marsh experienced 32 to 54 percent of its total handling capacity. The system's ability to accommodate peak flows was difficult to predict because the residual storage factor from previous storms greatly influenced the peak runoff handling capacity.

Stormwater Inundation Areas

The areal extent of stormwater inundation based on water surface elevation is presented graphically in Figure 12. The greatest gain in area wetted by stormwater occurs between the elevations of 2.0 and 3.0 ft where the inundated area doubles from 12 to nearly 24 acres. This is primarily accounted for by the increasing inundation of broad gently-sloping areas in: (1) the southwest margin of the System A lagoon; (2) the overland flow section of System B; and (3) the vegetated southern perimeter of System C. Between 3.0 and 3.5 ft water elevation, the inundated area increases by only 16 percent, which occurs mainly along the pond and channel banks. An estimation of the wetland area before and during two storms is given in Table 12 based on National Geodetic Vertical Datum (NGVD) elevations.

TABLE 12. EXTENT OF STORMWATER INUNDATION

Parameter	STORM DATE	
	8 Feb 85	5 Mar 85
Water elevation before storm (ft, NGVD)	2.93	2.83
Wetted area at beginning of storm (ac)	22.99	22.31
Maximum water elevation during storm (ft, NGVD)	3.47	3.33
Maximum wetted area during storm (ac)	27.55	26.43
Additional Area inundated by storm (ac)	4.56	4.12

Storage Volume and Estimated Residence Time

Stormwater residence time within the DUST Marsh system is a function of the storage volume before each storm and the inflow rate or total runoff volume of each storm. The cumulative storage volume is shown in Figure 13. The greatest storage capacities occur in the System A lagoon and the deep channel in System C. Due to the large storage capacity of the total system, large pulses of runoff water -- such as those occurring during a storm -- accumulate at a faster rate within the system than are discharged out the end of the marsh. Thus, total stormwater volume entering the marsh would be more relevant than instantaneous inflow rate for the calculation of residence time. An estimate of stormwater residence time for two storms is given in Table 13.

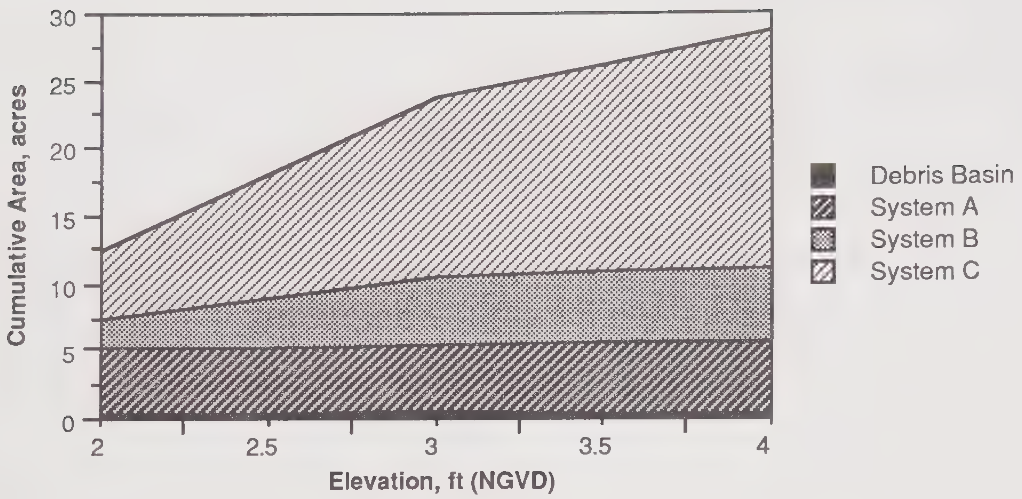


FIGURE 12. MARSH INUNDATION AREAS

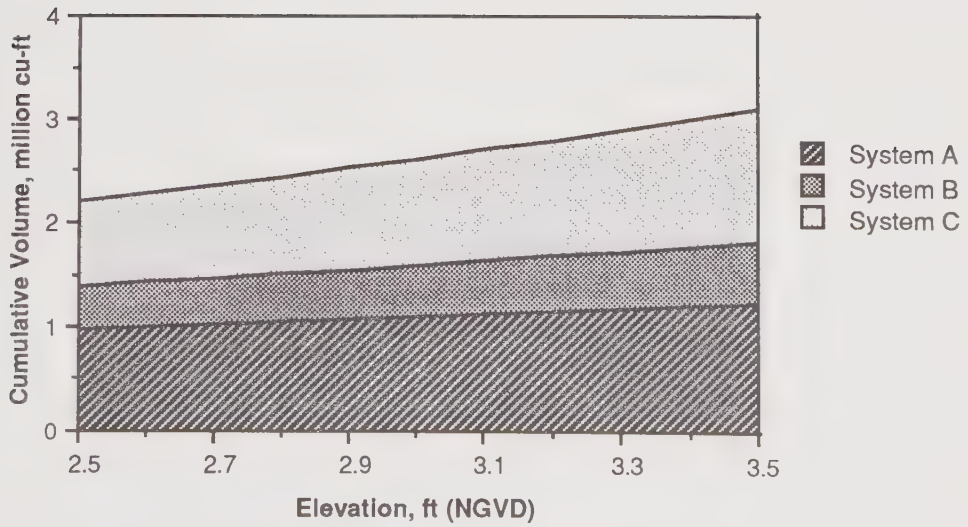


FIGURE 13. MARSH SYSTEM VOLUMES

TABLE 13. ESTIMATED STORAGE VOLUMES

Parameter	STORM DATE 8 Feb 85	5 Mar 85
Water elevation before storm (ft, MSL)	2.93	2.83
Pre-storm marsh volume (ft^3)	2.56×10^6	2.51×10^6
Stormwater volume entering marsh (ft^3)	1.39×10^6	1.30×10^6
Residual of pre-storm marsh volume (ft^3)	1.17×10^6	1.21×10^6

The water elevation at the beginning of each storm varies in relation to the inflow rate and elapsed time since the previous storm. Since the DUST Marsh system characteristically fills up rapidly during storms and discharges slowly over a long period, short intervals between storms can result in higher water levels. During Winter 1984-85, the between-storm water level was observed to vary between 2.85 and 2.95 ft, thus the minimum stormwater inflow would raise marsh volume by approximately 2.49×10^6 ft^3. Stormwater inflow would have to displace or "push out" the pre-storm storage volume before discharging to the marsh outlets. This assumes an ideal plug-flow situation where the stormwater inflow does not mix with the water in the system.

From Table 13, the inflow volumes on the 8 February and 5 March storms were insufficient to displace all of the marsh volume that existed before the storms. During February 1984, the estimated inflow rate to the marsh between storms was 6.05×10^4 ft^3/day. At that rate, following the 8 Feb 85 storm, an additional 42 days would be required to displace the residual storage volume. Similarly, for the 5 Mar 85 storm, the residence time of the residual storage volume from that storm would also have been 42 days until complete discharge. However, the occurrence of another large storm within 4 days brought in enough water to push out the previous storm's water and shorten the residence time to 4 days beyond the 5 Mar 85 storm period.

From an examination of observed stormwater inflow volumes in Table 11, only 2 monitored storms (24 Nov 85 and 24 Feb 86) generated sufficient flows (>2.2×10^6 ft^3) to potentially displace the pre-storm storage volumes. The remainder of the storms generated volumes on the order of the examples in Table 12.

Under actual field conditions, the influent stormwater may be subject to a combination of plug flow and mixing, complicated by stratification, and bypassing of some areas -- all factors that can greatly decrease or increase the travel time through the marsh. Field techniques such as dye-dispersion or current drifting (drogue) studies would yield a more accurate picture of marsh hydrology.

TIME OF TRAVEL -- DYE STUDY

Dye Study Results

A graph of initial dye concentrations from T0 to T45 for Stations A-2, B-2 and C-2 are shown in Figure 14. Since detectable dye levels continued beyond the 3 Feb 86 stormwater discharge cycle, a plot of dye concentrations for 14 days after the initial dye injection is shown in Figure 15. A hydrograph and rainfall intensity graph for the monitored storm are shown in Figure 16. A summary of the time-of-travel measurements is presented in Table 14.

The interpolated dye concentration curve between days 2 and 10 represents a linear decrease because no samples were taken during that period. However, from Figure 16, system outflow had dropped sharply by hour 50 and the residual dye remained within the system. Thus the dye concentration curve between storms would probably have remained relatively high. Reduction in dye concentrations due to dilution effects from between-storm inflows might have been offset by small releases of dye absorbed onto the sediments.

As the dye clouds traveled downstream, they continuously diffused, taking longer to pass the next site, while the peak or maximum concentrations decreased also. Table 14 gives the time for the entire dye cloud to pass each site, from leading edge to approximate trailing edge of detectable dye concentrations. In this study, the lower limit of dye detectability was about 5.0 ug/l (microgram per liter). The most significant conclusion of this part of the study was that stormwater (marked with dye in this case) remained within the DUST Marsh system beyond the initial stormwater flow cycle well into the next succeeding stormwater flow cycle.

Systems A and B exhibit a rapid rise from time of leading edge to time of peak dye concentration. After the peak is reached, however, the dye concentration decreases slowly as storage within systems increases and flows back up through the system and become sluggish. Typically, the tail end of the dye concentration curve becomes long and drawn out in slow-moving streams or areas with emergent vegetation. In contrast, ponds and lakes can yield broad curves with little attenuation in dye concentration if the dye remains within the system (Chase and Payne, 1970; Wilson, 1967).

Figure 14. Dye Concentration, 3-4 Feb 1986

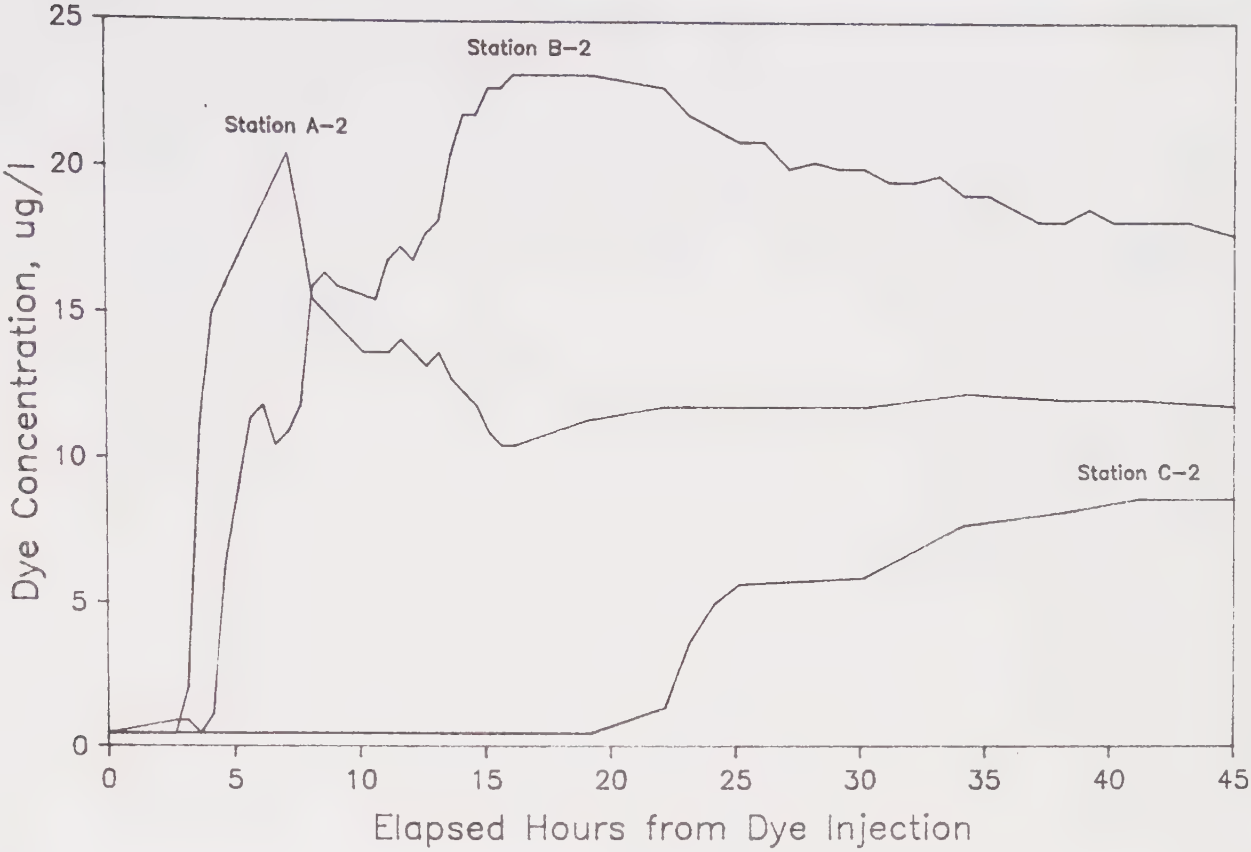


Figure 15. Dye Concentration, 3-17 Feb 1986

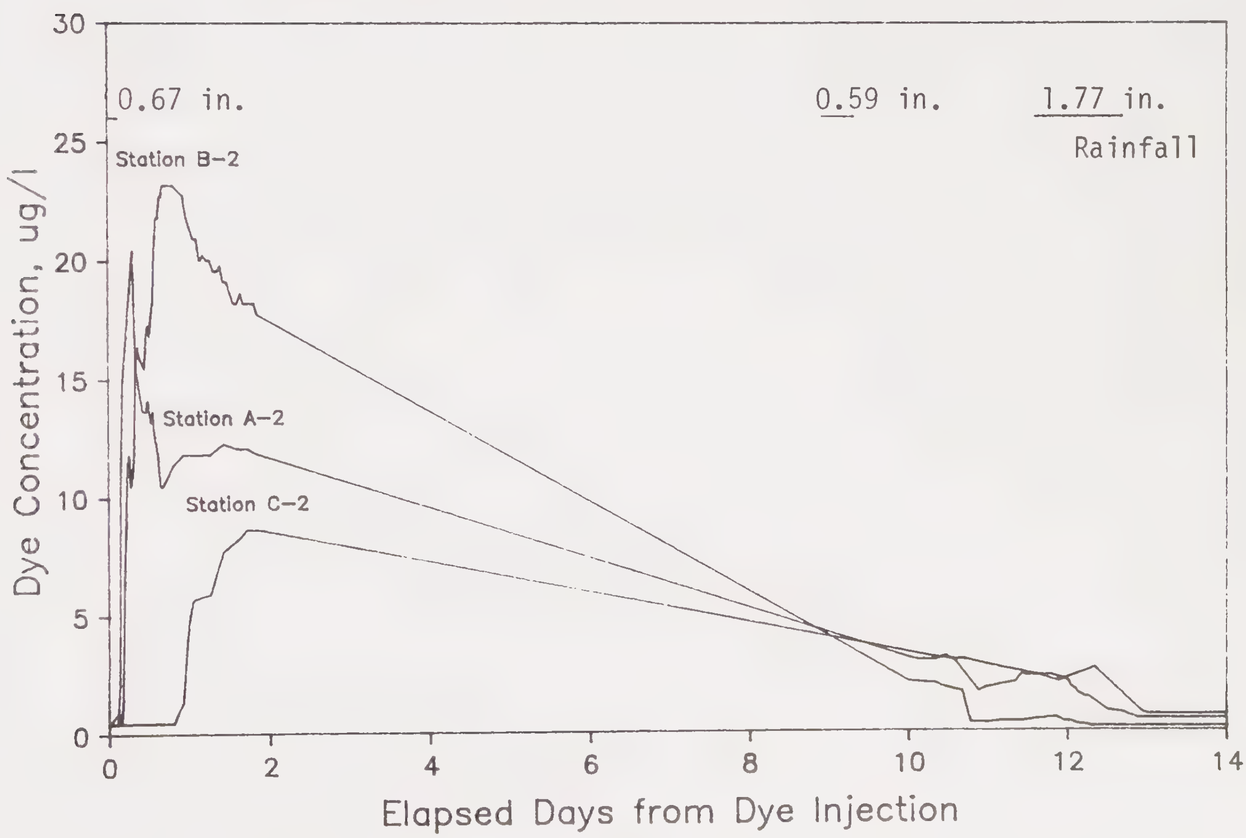
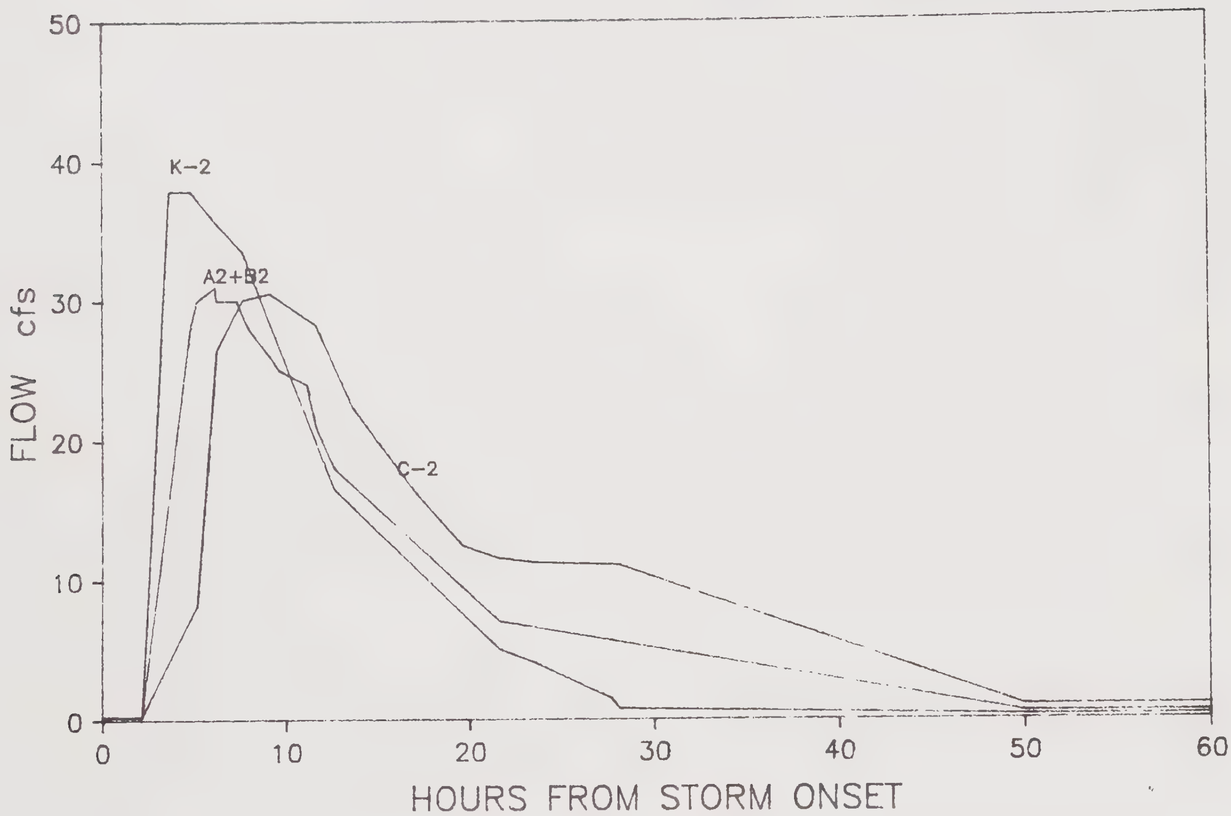


Figure 16. Storm Hydrograph, 3 Feb 1986



RAINFALL INTENSITY

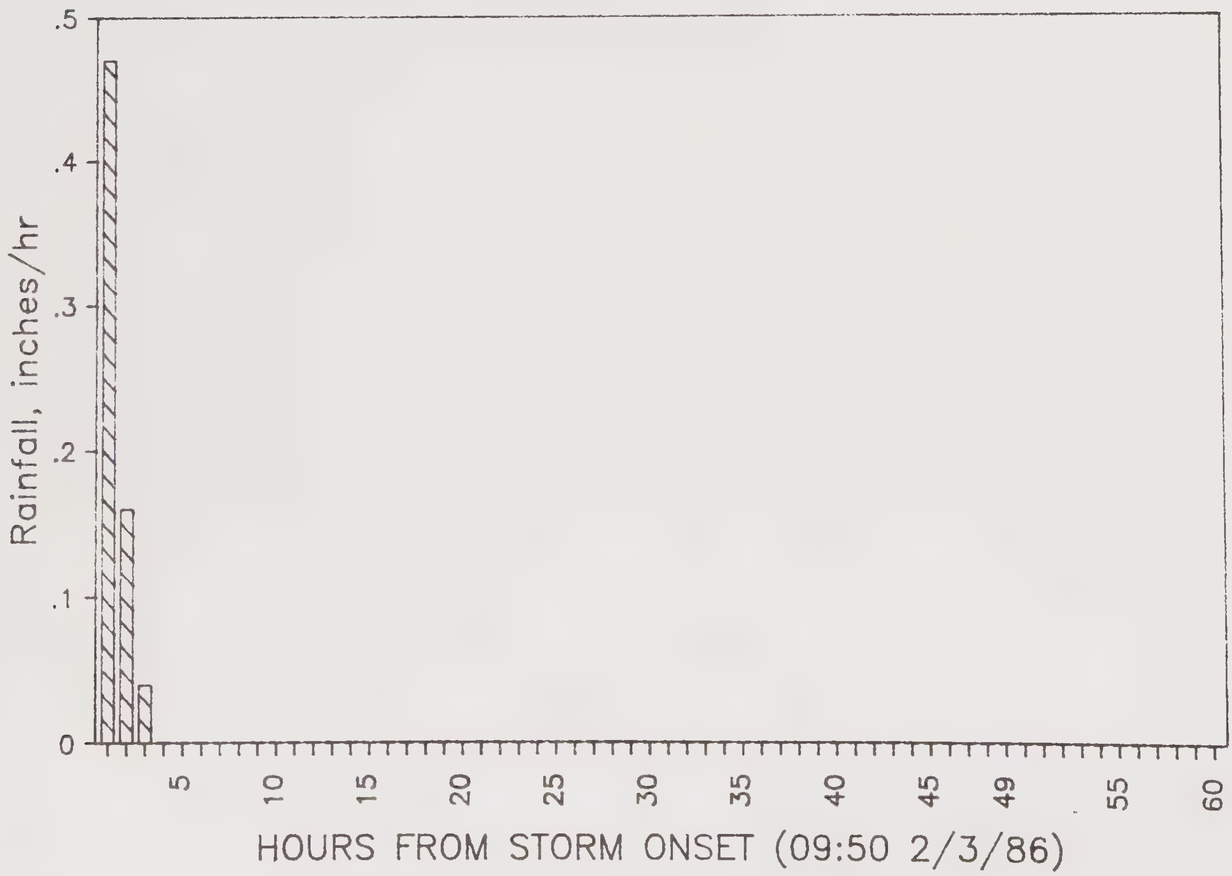


TABLE 14. SUMMARY OF TIME-OF-TRAVEL DATA
3-17 FEBRUARY 1986

Parameter	Station A-2	Station B-2	Station C-2
Distance downstream from Station K-2 (ft)	1260	1390	3860
Total Runoff Volume (10^6 ft^3)	0.90	0.68	1.58
Peak discharge rate (ft^3/s)	19.7	10.6	12.9
Cumulative travel time of dye cloud			
Leading edge (hrs)	3.2	4.2	22.2
Peak concentration (hrs)	7.2	16.2	44.2
Centroid (hrs)	36	36	120
Mean velocity (ft/hr) of dye cloud from K-2*	17.5	19.3	32.2
Time for dye cloud to pass site (days)	12.5	11	12
Observed peak dye concentration (ug/l)	20.0	22.7	8.2

* Travel time of centroid (center of dye cloud mass)

Interaction with P-Line Flows

Near the outlet of the DUST Marsh at the west end of System C is an ongoing construction project by a private developer in coordination with the ACFCD. This project, the "Ardenwood Development," involves the development of approximately 2000 acres south of and adjacent to the K-Line/Crandall Creek drainage area. Surface runoff from this development is conveyed down an open drainage channel -- designated "P-Line" by the ACFCD -- that meets the DUST Marsh near the terminus of System C. As shown in Figure 17, three 18-in. pipes were installed in the System C levee to convey P-Line storm flows into the DUST Marsh. P-Line flows would mingle with System C water and when the water elevation rose above 2.7 ft, the combined flows would discharge out the 58-in. outlet pipe on the opposite side of System C to North Marsh.* In addition, one 330-ft long, 18-in. diameter pipe was installed to bypass a portion of the P-Line flows around System C directly into North Marsh. All of the 18-in. P-Line pipes are governed by manual slide gates, which control the distribution of P-Line water to either the DUST Marsh or North Marsh or both simultaneously. During Winter 1984-85, the gates were not installed and water flowed freely through all four pipes. During Winter 1985-86, the gates were installed and were open all winter.

If the Ardenwood Development and P-Line were fully constructed and operational, then P-Line stormflows would enter System C with peak flows probably occurring 1 to 6 hours after the start of the storm. Since the DUST Marsh accumulates stormwater faster than the average marsh discharge rate, P-Line water would probably back-up within System C and cause upstream flows within the DUST Marsh System to back-up as well. The results would potentially be:

- o An increase in total area inundated by stormwater;
- o An increase in total stormwater volume entering the marsh;
- o An increase in K-Line stormwater residence time;
- o An increase in between-storm water elevations within the marsh; and
- o Mixing of P-Line and System C waters to some extent upstream of the outlet pipes, thereby affecting the interpretation of water quality analyses at Station C-2.

During Winter 1984-85, the actual runoff volume in P-Line was much less than anticipated because construction of the Ardenwood project had not yet begun. By Winter 1985-86, less than 10 percent of Ardenwood had been constructed. Stormflows in the P-Line channel were relatively small and did not create enough head (water height) compared to System C to flow

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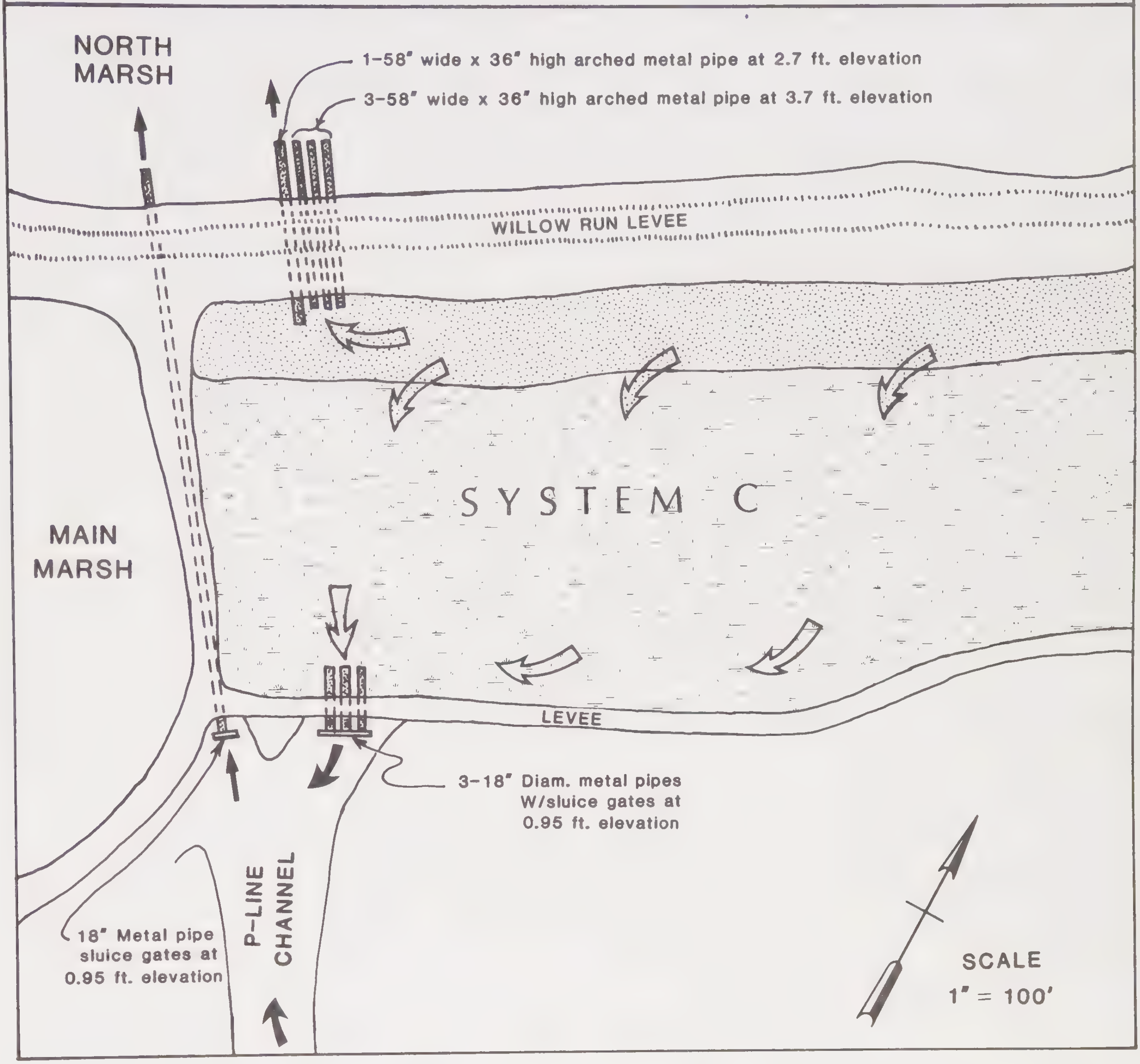
* The pipe inlet elevation was designed at elevation 2.0 ft, but during construction, was actually installed at approximately 2.7 ft.

Figure 17 System C Outlet Configuration



into the DUST Marsh. Instead, the relative water elevation was always higher in System C, and the DUST Marsh typically drained through the 330-ft long bypass pipe into North Marsh. This reverse-flow pattern was observed throughout the winter and, apparently, no P-Line water entered the DUST Marsh. Due to the high exit elevation (2.7 ft) on the opposite side of System C, significant flows would be required in the P-Line to drive flows through System C. As the Ardenwood Development continues and more impervious surface areas (roofs, yards, parking lots and streets) are constructed, runoff can be expected to increase to the threshold volume needed to drive P-Line flows through the DUST Marsh.

SECTION 4
STORM WATER QUALITY

One of the original research objectives of the DUST Marsh Project was the detailed, storm-by-storm comparison of the treatment capabilities of two different systems: System A (a 5-ac pond) and System B (two ponds, 0.5 and 2.0 ac). The two systems are separated by three acres of overland flow.

This type of analysis assumes that an element of flow into the marsh can be correlated with an element of flow out of the marsh. For the DUST Marsh, this correlation has proven to be difficult due to factors such as a large between-storm storage volume variations and lack of information on areas of poor water circulation in the marsh. It was anticipated that the dye study performed in February 1986 would provide a precise estimate of the hydraulic detention within the various components of the marsh system. However, the variation due to non-uniform system configurations such as combination overland flow and pond systems lead to difficult-to-characterize flow patterns in the marsh. Due to these complicated flow patterns, it is uncertain that water flowing out of the DUST Marsh during a given storm is the same water that flowed into the marsh earlier in the day. At any given time, water flowing out of System C is undoubtedly of mixed origin - a portion may have its genesis in the current storm, while some other, indeterminate fraction is contributed by water stored from a previous storm. For that reason, a storm-by-storm analysis of the data is probably not appropriate.

In order to account for changes in pollutant loadings that span more than one storm, the comparison for water quality treatment was revised to a seasonal mass loading basis. Listed below are some conclusions about marsh hydrology from the dye study. These conclusions provide our rationale for using the seasonal approach to evaluate mass loadings.

1. Due to the large system storage capacity and small outlet structures, peak stormwater flows accumulate rapidly within the system and are discharged slowly over a periods of days or weeks -- if the interval between storms is long.

2. Stormwater runoff entry into the marsh system partially "pushes out" the existing storage volume and becomes resident until the next pulse of runoff water displaces it. More than one subsequent storm event may be required to push out the first storm volume. Thus, water collected at Station C-2 during a storm is probably representative of water that entered from the previous storm.

3. The treatment cycle in the marsh system spans several storms, with no one storm providing a complete picture of pollutant loading, system processing and effluent treatment.

4. The accumulation of loadings and discharge levels from many storms would account for the prolonged treatment cycle and provide a more complete picture of the marsh treatment function over an entire winter storm season.

Four storms were monitored in Winter 1984-85 and seven storms in Winter 1985-86 -- a total of 11 storms. For each storm, the results of the analysis from the composited samples were flow-weighted to develop storm-period loadings from the 4 stations within the Marsh. The composite analysis data is presented in Appendix B. Individual storm loadings, by analysis parameter, are presented on Table 15. A summary of the seasonal mass loadings (based on the totals of the monitored storms for each season) and comparisons of change among parameters is shown in Tables 16 through 19.

The 1984-85 mass loading results are subject to wide variability because operational problems occurred (refer to Section 3 - Hydrology) requiring reconstruction of the storm hydrograph from representative data. In addition, only four storms were monitored during that season -- as compared to seven storms the following winter. Data collected during Winter 1985-86 was more comprehensive and changes in system loadings for that season are presented in Figure 18.

For almost all of the parameters measured, the marsh system provided excellent treatment, especially in its uptake of heavy metals. Some anomalies exist in the data. Some are not easily explained and some are inconsequential. For instance, at a first glance, it is alarming to note that BOD5 appears to have increased 35 percent. However, since the inflow concentration is only a few milligrams per liter, the increase, though unexplained, is insignificant.

Salinity

The high variance in pH, electrical conductivity and total dissolved solids (TDS) cannot be explained by stormwater inputs alone. The increase in TDS indicates probable salinity inputs occurring within the marsh system. This could be attributed to either leaching effects from saline soils or intrusion of saline groundwater into the marsh system.

The lands within Systems A and B were previously used for agriculture. A historic regimen of irrigation with fresh-to-brackish water and high seasonal evaporation rates led to a gradual accumulation of salts in the upper soil layers. Marsh construction activities in 1982-84 and subsequent inundation, particularly over all of System B, exposed these saline soils and caused probable leaching from the soil into the overlying surface waters. However, an examination of groundwater conductivity in Figure 19 (Section 5 - Dry Season and Groundwater Quality) as well as soil conductivity in Table 26 (Section 7 - Soil and Sediment) shows low conductivity and low chloride concentrations in System B, which is indicative of only moderately brackish water compared to Systems A and C. Thus leaching effects from saline soils in Systems A and B are probably not the main cause of the salinity variation.

The historical extent of tidal or salt marshes in San Francisco Bay encompasses a portion of Coyote Hills Park. Nichols and Wright (1971) mapped the eastern boundary of the tidal marsh as occurring within the Main Marsh area. Although the DUST Marsh site was not included in that zone, its close proximity to Main Marsh suggests a possible relationship. An

Table 15. DUST MARSH MASS LOADINGS

DUST MARSH MASS LOADING: 5 DAY BOD

STORM	STATION: K-2 CONCENTRATION (MG/L) RANGE	AVG	LOADING (KG)	STATION: A-2 CONCENTRATION (MG/L) RANGE	AVG	LOADING (KG)	STATION: B-2 CONCENTRATION (MG/L) RANGE	AVG	LOADING (KG)	STATION: C-2 CONCENTRATION (MG/L) RANGE	AVG	LOADING (KG)
12 NOV 1984	2.2-2.5	2.36	242	3.1-4.3	3.54	146	2.7-3.7	2.94	182	3.5-4	3.90	400
27 NOV 1986	2.5-3.3	3.39	192	3.8-4.7	4.39	114	3.1-3.9	3.54	138	4.4-10	7.53	488
8 FEB 1985	1.1-3.2	2.87	113	3.4-5.4	3.79	99	2.4-6.0	3.06	54	2.6-6.2	3.38	148
5 MAR 1985	5.1-6.8	5.31	249	5.5-9.6	7.39	227	6.4-9.4	8.03	166	6.6-8.8	7.63	392
24 NOV 1985	4.7-5.9	5.13	333	5.1-9.1	6.49	261	5.2-8.2	6.05	163	6.8-10	7.47	483
3 JAN 1986	2.6-6	4.30	141	3.3-8.9	5.34	108	3.0-6.0	3.90	53	1.8-4.8	2.67	91
29 JAN 1986	1.7-3.4	2.93	47	4.9-5.8	7.47	49	4.4-6.3	5.83	38	3.3-5.0	4.74	60
31 JAN 1986	************************ BELOW DETECTION LEVEL ************************									2.7-5.4	4.41	171
12 FEB 1986	1.3-5.1	4.22	139	2.3-3.9	2.85	56	2.1-4.5	2.56	34	4.2-4.8	4.42	144
14 FEB 1986	2.4-6.2	2.99	209	2.4-3.2	2.76	64	2.2-2.7	2.76	90	2.4-2.8	2.56	191
7 MAR 1986	1.2-6.8	4.31	200	9.2-11	9.83	272	7.0-9.2	7.61	142	3.5-7.5	6.54	300

DUST MARSH MASS LOADING: NITROGEN AS NH3

STORM	STATION: K-2 CONCENTRATION (MG/L) RANGE	AVG	LOADING (KG)	STATION: A-2 CONCENTRATION (MG/L) RANGE	AVG	LOADING (KG)	STATION: B-2 CONCENTRATION (MG/L) RANGE	AVG	LOADING (KG)	STATION: C-2 CONCENTRATION (MG/L) RANGE	AVG	LOADING (KG)
12 NOV 1984	.45-.53	.487	50	.29-.35	.33	13.7	.28-.35	.33	20.3	.23-.47	.31	31.7
27 NOV 1984	.18-.44	.371	21	.45-.95	.69	18	.09-.47	.36	14	.19-.58	.50	32.4
8 FEB 1985	.18-.89	.345	13.6	.26-.44	.36	9.4	.18-.41	.24	4.2	.2-.4	.20	8.8
5 MAR 1985	.53-1.5	.601	28.2	.29-1.52	.73	22.4	.39-.86	.67	13.9	.02-.12	.31	15.8
24 NOV 1985	.41-.69	.524	34	1.2-1.9	1.51	60.5	.11-.95	.28	7.5	.22-.63	.32	20.8
3 JAN 1986	1.1-1.7	1.59	52.1	.53-.88	.65	13.1	.55-.85	.92	12.5	.8-.96	1.02	34.6
29 JAN 1986	.4-1.1	.596	9.5	.38-1.6	.73	7	.55-.84	.64	4.2	.37-1.1	.58	7.4
31 JAN 1986	**********	471.	18,848	490-990	534.87	12,797	400-670	524.47	7,822	620-1000	701.46	27,044
12 FEB 1986	.16-.57	.240	7.9	.29-.88	.47	9.3	.14-.4	.20	2.7	.26-.85	.43	14
14 FEB 1986	.1-.41	.160	11.2	.25-.63	.46	10.6	.19-.53	.34	11.2	.32-.92	.55	41
7 MAR 1986	.36-1.2	.549	25.5	.14-.5	.33	9.1	.14-.34	.30	5.6	.23-.5	.38	17.3

Table 15. DUST MARSH MASS LOADINGS continued

DUST MARSH MASS LOADING: PHOSPHORUS AS PO4

STORM	STATION: K-2			STATION: A-2			STATION: B-2			STATION: C-2		
	CONCENTRATION (MG/L)		LOADING (KG)	CONCENTRATIO (MG/L)		LOADING (KG)	CONCENTRATION (MG/L)		LOADING (KG)	CONCENTRATION (MG/L)		LOADING (KG)
	RANGE	AVG		RANGE	AVG		RANGE	AVG		RANGE	AVG	
12 NOV 1984	.3-.4	.301	30.9	.06-.45	.09	3.7	.08-.25	.140	8.7	.08-.1	.094	9.7
27 NOV 1984	.07-.24	3.82	216	.02-.11	.09	2.4	.02-.19	.136	5.3	.009-.02	.010	.62
8 FEB 1985	.02-.17	.148	5.85	<.01-.12	.10	2.54	<.01-.15	.113	2	<.01-.08	.068	3
5 MAR 1985	.03-.16	.132	6.2	<.01-.01	.01	.279	.01-.02	.011	.235	<.01-.01	.01	.504
24 NOV 1985	.22-.25	.236	15.3	.07-.14	.12	4.83	.08-.18	.138	3.71	.08-.13	.158	6.9
3 JAN 1986	.17-.46	.312	10.3	.09-.12	.10	2	.09-.12	.118	1.6	.09	.09	3.1
29 JAN 1986	.08-.15	.109	1.73	.06-.13	.10	.93	.09-.13	.101	.66	.06-.08	.078	.99
31 JAN 1986	.16-.22	.205	8.2	.08-.1	.10	2.12	.08-.16	.153	2.3	.08-.1	.095	3.5
12 FEB 1986	.12-.42	.337	11.1	.13-.15	.14	2.7	.13-.18	.166	2.2	.08-.09	.089	2.9
14 FEB 1986	.14-.71	.232	16.2	.11-.42	.23	5.4	.14-.51	.310	10.1	.1-.18	.123	9.2
7 MAR 1986	.04-.24	.125	5.83	.02-.07	.05	1.45	.01-.22	.091	1.69	.022-.45	.075	3.45

DUST MARSH MASS LOADING: TOTAL PHOSPHORUS

STORM	STATION: K-2			STATION: A-2			STATION: B-2			STATION: C-2		
	CONCENTRATION (MG/L)		LOADING (KG)	CONCENTRATIO (MG/L)		LOADING (KG)	CONCENTRATION (MG/L)		LOADING (KG)	CONCENTRATION (MG/L)		LOADING (KG)
	RANGE	AVG		RANGE	AVG		RANGE	AVG		RANGE	AVG	
12 NOV 1984	.64-3.1	1.41	145	.19-.37	.33	13.7	.12-1.26	.525	32.5	.32-.39	.363	37.3
27 NOV 1984	.28-1.5	1.01	57	.18-.82	.42	11	.18-.98	.467	18.2	.14-.21	.150	9.7
8 FEB 1985	.04-.55	.413	16.3	.18-.3	.28	7.2	.17-.34	.301	5.3	.11-.26	.237	10.4
5 MAR 1985	.15-.36	.352	16.5	.13-.22	.14	4.4	.13-.23	.176	3.1	.13-.39	.409	17.9
24 NOV 1985	.35-.46	.416	27	.24-.39	.35	13.9	.28-.46	.401	10.8	.28-.42	.381	24.6
3 JAN 1986	.27-.84	.579	19	.27-.31	.29	5.9	.24-.35	.316	4.3	.13-.18	.150	5.1
29 JAN 1986	.15-.37	.257	4.1	.14-.21	.18	1.7	.15-.22	.206	1.35	.13-.17	.165	2.1
31 JAN 1986	.31-.85	.760	30.4	.17-.73	.62	13.7	.18-.56	.517	7.4	.18-.3	.279	10.5
12 FEB 1986	.17-.71	.558	18.4	.24-.35	.31	6	.3-.39	.324	4.3	.14-.17	.150	4.9
14 FEB 1986	.32-1.4	.584	40.8	.34-3	1.3	30.5	.37-3.4	1.70	55.4	.23-.41	.291	21.7
7 MAR 1986	.12-.78	.280	13	.11-.2	.14	4	.14-.3	.204	3.8	.18-.6	.233	10.7

Table 15. DUST MARSH MASS LOADINGS continued

DUST MARSH MASS LOADING: NITROGEN AS NO3

STORM	STATION: K-2 CONCENTRATION (MG/L) RANGE	AVG	LOADING (KG)	STATION: A-2 CONCENTRATION (MG/L) RANGE	AVG	LOADING (KG)	STATION: B-2 CONCENTRATION (MG/L) RANGE	AVG	LOADING (KG)	STATION: C-2 CONCENTRATION (MG/L) RANGE	AVG	LOADING (KG)
12 NOV 1984	2-3.1	2.54	261	.82-1.8	1.14	47.2	.85-2.6	1.46	90.5	.93-1	.98	101
27 NOV 1984	1.1-7.8	3.64	206	2.1-3.1	2.73	71	2.1-3.1	2.69	105	1.4-2.2	2.05	133
8 FEB 1985	.69-2.9	1.03	40.5	.34-1.1	.73	19	.42-2.4	1.28	22.6	.27-1.27	1.19	52.3
5 MAR 1985	.81-1.8	1.19	55.6	.3-1	.69	14.3	.3-1	.44	9	.59-2	.77	39.8
24 NOV 1985	1.3-2	2.03	132	.62-1.5	1.17	46.9	.42-1.9	1.40	37.7	.25-1.1	.91	59.1
3 JAN 1986	1.6-2.8	2.84	57.3	2.6-3.2	2.89	58.3	2.3-3.9	2.74	37.3	2.3-2.4	2.39	81.2
29 JAN 1986	.4-3.4	1.72	27.4	2.9-4.2	3.45	33.2	1.3-2.4	2.04	13.4	1.4-2.9	1.55	19.8
31 JAN 1986	1.2-1.7	1.55	62.1	1.9-2.6	2.05	47.9	1.5-2.1	1.55	23.8	1.9-2.1	2.05	76.3
12 FEB 1986	1.7-11.1	4.79	158	3.5-4	3.84	75.4	3.9-4.9	4.19	55.6	1.5-2.5	1.88	61.3
14 FEB 1986	1.5-3.9	2.36	165	2.9-4.2	3.53	81.8	1.5-4.1	2.24	73.2	2.1-3.4	2.92	218
7 MAR 1986	1.1-10	5.86	272	4.6-5.1	4.81	133	2-7	4.79	89.4	1.7-5.1	4.27	196

DUST MARSH MASS LOADING: KJELDAHL NITROGEN

STORM	STATION: K-2 CONCENTRATION (MG/L) RANGE	AVG	LOADING (KG)	STATION: A-2 CONCENTRATION (MG/L) RANGE	AVG	LOADING (KG)	STATION: B-2 CONCENTRATION (MG/L) RANGE	AVG	LOADING (KG)	STATION: C-2 CONCENTRATION (MG/L) RANGE	AVG	LOADING (KG)
12 NOV 1984	2.5-3.1	2.82	289	1.4-2.2	1.95	80.4	1.1-2.1	1.87	116	.9-1.9	1.71	176
27 NOV 1984	2.5-3.9	3.83	217	2-3	2.38	61.9	1.8-3.8	2.85	111.1	2.6-3.4	2.87	186
8 FEB 1985	.91-1.8	1.14	45.1	.93-1.6	1.22	31.9	1-2.1	1.29	22.7	.89-1.2	1.16	50.6
5 MAR 1985	1.2-3.4	1.37	64.3	1.9-3.4	2.00	61.3	2-4.2	2.37	49.1	.59-2	.77	39.8
24 NOV 1985	1.6-4	2.14	139	.68-4.2	1.69	68	2.2-3.6	2.45	66	2.2-4.7	3.23	209
3 JAN 1986	1.5-2.5	1.86	61	1.5-2.7	1.88	38	1.4-3.1	2.07	28.1	1.1-2.7	2.09	71.1
29 JAN 1986	.21-1.8	.978	15.6	1.3-2.9	1.57	15.1	1.5-3.1	2.40	15.7	.61-2.9	2.26	28.8
31 JAN 1986	1.8-3.2	2.88	115	1.6-2.1	1.96	43.1	1.5-2.1	1.93	29.6	1.5-3.1	1.95	72.5
12 FEB 1986	.96-2.5	2.15	70.8	1.4-2.3	1.64	32.1	1-2.2	1.77	23.5	2-3.1	2.73	89
14 FEB 1986	1.1-2.5	2.02	141	2-3.5	2.91	67.5	1.1-3.8	3.05	99.6	1.8-3	2.73	204
7 MAR 1986	.15-2.3	.944	43.8	1.8-3	2.21	61.1	2.1-3	2.45	45.7	.41-2.3	1.53	70.2

Table 15. DUST MARSH MASS LOADINGS continued

DUST MARSH MASS LOADING: OIL AND GREASE

STORM	STATION: K-2 CONCENTRATION (MG/L) RANGE	AVG	LOADING (KG)	STATION: A-2 CONCENTRATIO (MG/L) RANGE	AVG	LOADING (KG)	STATION: B-2 CONCENTRATION (MG/L) RANGE	AVG	LOADING (KG)	STATION: C-2 CONCENTRATION (MG/L) RANGE	AVG	LOADING (KG)
12 NOV 1984	.3-.4	.330	33.9	.5-.8	.67	27.5	.3-1.1	.738	45.7	.5-1.3	1.09	112
27 NOV 1984	.5-.9	.816	46.2	.09-1	.69	17.9	.09-.8	.629	24.5	.09-.6	.450	29.2
8 FEB 1985	.087-.4	.241	9.5	1.3-1.61	1.6	41.8	1.3-1.7	1.46	25.8	1.2-1.8	1.27	55.8
5 MAR 1985	.7-1.3	1.07	50.1	.8-1.7	.83	21.7	.2-.8	.484	10	.3-.4	.547	28.1
24 NOV 1985	.8-2.1	1.45	94.2	.5-2.5	2.1	83.9	.8-1.9	1.37	36.8	.5-1.3	1.04	67
3 JAN 1986	BELOW DETECTION LEVEL											
29 JAN 1986	.4-1.8	.834	13.3	.4-.6	.57	5.5	.4-.8	.519	3.4	.4-.5	.486	6.2
31 JAN 1986	BELOW DETECTION LEVEL											
12 FEB 1986	.9	.9	29.7	.4	.4	7.3	.4-1.1	.565	7.5	.4	.4	13
14 FEB 1986	.4-.5	.409	28.6	.4-.9	.57	13.2	.4-.9	.616	20.1	.4-.9	.488	36.4
7 MAR 1986	NOT ANALYZED FOR OIL AND GREASE											

DUST MARSH MASS LOADING: CADMIUM

STORM	STATION: K-2 CONCENTRATION (MG/L) RANGE	AVG	LOADING (KG)	STATION: A-2 CONCENTRATION (MG/L) RANGE	AVG	LOADING (KG)	STATION: B-2 CONCENTRATION (MG/L) RANGE	AVG	LOADING (KG)	STATION: C-2 CONCENTRATION (MG/L) RANGE	AVG	LOADING (KG)
12 NOV 1984	BELOW DETECTION LEVEL											
27 NOV 1984	BELOW DETECTION LEVEL											
8 FEB 1985	BELOW DETECTION LEVEL											
5 MAR 1985	SAMPLES NOT ANALYZED FOR CADMIUM											
24 NOV 1985	<.002-.004	.002	.136	<.002-.007	.002	.08	<.002-.013	.037	.99	<.002-.004	.001	.096
3 JAN 1986	BELOW DETECTION LEVEL											
29 JAN 1986	BELOW DETECTION LEVEL											
31 JAN 1986	BELOW DETECTION LEVEL											
12 FEB 1986	BELOW DETECTION LEVEL						.02-.03	.028	.37	.01	.01	.33
14 FEB 1986	BELOW DETECTION LEVEL											
7 MAR 1986	BELOW DETECTION LEVEL						<.002-.004	.001	.024	BELOW DETECTION LEVEL		

Table 15. DUST MARSH MASS LOADINGS continued

DUST MARSH MASS LOADING: CHROMIUM

STORM	STATION: K-2 CONCENTRATION (MG/L) RANGE	AVG	LOADING (KG)	STATION: A-2 CONCENTRATION (MG/L) RANGE	AVG	LOADING (KG)	STATION: B-2 CONCENTRATION (MG/L) RANGE	AVG	LOADING (KG)	STATION: C-2 CONCENTRATION (MG/L) RANGE	AVG	LOADING (KG)
12 NOV 1984	<.005-.008	.006	.6	***************************** BELOW DETECTION LEVEL *****************************								
27 NOV 1984	<.005-.007	.006	.35	***************************** BELOW DETECTION LEVEL *****************************								
8 FEB 1985	<.005-.015	.012	.47	<.005-.022	.011	.28	<.005-.01	.008	.14	<.005-.01	.009	.39
5 MAR 1985	.006-.024	.023	1.06	.006-.012	.006	.17	<.005-.01	.006	.11	.009-.01	.010	.51
24 NOV 1985	.04-.058	.051	3.32	.017-.052	.043	1.73	.016-.068	.054	1.45	<.005-.036	.021	1.33
3 JAN 1986	.030-05	.037	1.23	.02-.03	.023	.47	.03-.05	.040	.55	.01-.02	.012	.4
29 JAN 1986	.01-.03	.026	.42	.01-.02	.014	.13	.01-.02	.017	.11	.01-.02	.016	.21
31 JAN 1986	.03-.11	.100	4	.03-.08	.059	1.37	.04-.08	.079	1.24	.01-.03	.018	.71
12 FEB 1986	.02-.05	.024	.8	.03-.04	.032	.62	.02-.03	.022	.29	.01-.02	.015	.49
14 FEB 1986	.02-.09	.055	3.83	.01-.07	.042	.97	.01-.05	.032	1.04	.01-.03	.019	1.41
7 MAR 1986	.01-.17	.043	1.98	.01-.02	.013	.36	.01-.03	.018	.33	.01	.01	.46

DUST MARSH MASS LOADING: COPPER

STORM	STATION: K-2 CONCENTRATION (MG/L) RANGE	AVG	LOADING (KG)	STATION: A-2 CONCENTRATION (MG/L) RANGE	AVG	LOADING (KG)	STATION: B-2 CONCENTRATION (MG/L) RANGE	AVG	LOADING (KG)	STATION: C-2 CONCENTRATION (MG/L) RANGE	AVG	LOADING (KG)
12 NOV 1984	.009-.01	.010	.1	.01	.01	.41	.009-.01	.010	.6	.007-.01	.008	.79
27 NOV 1984	.009-.01	.01	.6	.01-.03	.015	.39	.009-.02	.013	.5	.01-.02	.014	.9
8 FEB 1985	<.01-.06	.010	.39	<.01-.01	.009	.24	<.01-.01	.010	.17	<.01-.01	.009	.39
5 MAR 1985	<.01-.01	.009	.42	<.01-.02	.009	.28	* BELOW DETECTION LEVEL *			<.01-.01	.009	.46
24 NOV 1985	<.01-.01	.012	.75	.01-.02	.018	.74	<.01-.02	.011	.3	<.01-.01	.009	.61
3 JAN 1986	.01-.02	.017	.56	.02-.03	.024	.48	.01-.02	.018	.25	.01-.02	.019	.63
29 JAN 1986	.01-.02	.016	.25	.01	.01	.096	.01	.01	.065	.01	.01	.13
31 JAN 1986	.01-.03	.027	1.08	.01-.03	.024	.57	.01-.02	.018	.29	.01	.01	.38
12 FEB 1986	.01-.02	.018	.58	.01-.02	.018	.36	.01	.01	.13	.01	.01	.33
14 FEB 1986	.01-.02	.016	1.14	.01-.02	.014	.32	<.01-.01	.010	.32	.01-.02	.013	.99
7 MAR 1986	.01-.05	.016	.76	.01-.02	.012	.34	.01-.02	.048	.29	.01	.01	.46

Table 15. DUST MARSH MASS LOADINGS continued

DUST MARSH MASS LOADING: LEAD

STORM	STATION: K-2 CONCENTRATION (MG/L) RANGE	AVG	LOADING (KG)	STATION: A-2 CONCENTRATION (MG/L) RANGE	AVG	LOADING (KG)	STATION: B-2 CONCENTRATION (MG/L) RANGE	AVG	LOADING (KG)	STATION: C-2 CONCENTRATION (MG/L) RANGE	AVG	LOADING (KG)
12 NOV 1984	<.005-.006	.005	.48	************* BELOW DETECTION LEVEL ***************						<.005-.021	.005	.52
27 NOV 1984	<.005-.01	.006	.36	* BELOW DETECTION LEVEL *			<.005-.013	.007	.29	* BELOW DETECTION LEVEL *		
8 FEB 1985	************ SAMPLES NOT ANALYZED FOR LEAD ************											
5 MAR 1985	.006-.012	.010	.49	<.005-.007	.004	.13	.005-.009	.005	.11	<.005-.005	.005	.25
24 NOV 1985	************ BELOW DETECTION LEVEL ************											
3 JAN 1986	.009-.02	.014	.47	.006-.008	.007	.14	<.005-.014	.007	.1	* BELOW DETECTION LEVEL *		
29 JAN 1986	************ BELOW DETECTION LEVEL ************8											
31 JAN 1986	.011-.02	.013	.52	.014-.024	.017	.4	.011-.022	.012	.19	<.005-.007	.006	.22
12 FEB 1986	<.005-.011	.007	.22	<.005-.005	.004	.079	<.005-.016	.005	.071	* BELOW DETECTION LEVEL *		
14 FEB 1986	<.005-.008	.005	.32	<.005-.008	.006	.13	.005-.009	.005	.16	* BELOW DETECTION LEVEL *		
7 MAR 1986	<.005-.008	.005	.25	************ BELOW DETECTION LEVEL ************								

DUST MARSH MASS LOADING: MANGANESE

STORM	STATION: K-2 CONCENTRATION (MG/L) RANGE	AVG	LOADING (KG)	STATION: A-2 CONCENTRATION (MG/L) RANGE	AVG	LOADING (KG)	STATION: B-2 CONCENTRATION (MG/L) RANGE	AVG	LOADING (KG)	STATION: C-2 CONCENTRATION (MG/L) RANGE	AVG	LOADING (KG)
12 NOV 1984	.01	.01	1	.15-10	5.91	244	.07-.1	.068	4.2	.46-.53	.468	48
27 NOV 1984	.01-.41	.152	8.6	.42-1.2	.720	18.7	.01-1.1	.272	10.6	1.4-2.2	1.65	107
8 FEB 1985	.04-1.8	.903	35.6	.23-1.5	.494	12.9	.2-1.4	.380	6.7	.38-1.4	.457	20
5 MAR 1985	.1-.23	.100	4.7	.4-.74	.674	20.7	.33-.68	.609	12.6	.46-.94	.500	25.7
24 NOV 1985	.14-.23	.194	12.6	.13-.3	.287	8.8	.18-.31	.245	6.6	.26-.45	.309	20
3 JAN 1986	.12-.25	.207	6.8	.16-.18	.160	3.2	.1-.18	.162	2.2	.16-.24	.217	7.4
29 JAN 1986	.12-.2	.151	2.4	.2-.35	.239	2.3	.28-.51	.320	2.1	.36-.63	.533	6.8
31 JAN 1986	.12-.43	.383	15.3	.16-.34	.286	6.7	.14-.34	.300	4.7	.19-.45	.312	12.1
12 FEB 1986	.12-.19	.127	4.2	.18-.35	.280	5.5	.1-.26	.184	2.4	.46-1.1	.920	30
14 FEB 1986	.1-.36	.200	14	.18-.31	.242	5.6	.02-.28	.138	4.5	.18-.46	.318	23.7
7 MAR 1986	.06-.72	.177	8.2	.3-.76	.521	14.4	.14-.22	.171	3.2	.28-1.4	.739	33.9

Table 15. DUST MARSH MASS LOADINGS continued

DUST MARSH MASS LOADING: NICKEL

STORM	STATION: K-2 CONCENTRATION (MG/L) RANGE	AVG	LOADING (KG)	STATION: A-2 CONCENTRATION (MG/L) RANGE	AVG	LOADING (KG)	STATION: B-2 CONCENTRATION (MG/L) RANGE	AVG	LOADING (KG)	STATION: C-2 CONCENTRATION (MG/L) RANGE	AVG	LOADING (KG)
12 NOV 1984	<.03-.04	.027	2.8	<.03-.05	.041	1.7	* BELOW DETECTION LEVEL *			<.02-.04	.021	2.2
27 NOV 1984	<.03-.11	.058	3.3	* BELOW DETECTION LEVEL *			<.03-.08	.059	2.3	<.03-.08	.022	2.3
8 FEB 1985	<.03-.04	.028	1.1	<.03-.08	.046	1.2	<.03-.05	.040	.71	.02-.04	.022	.96
5 MAR 1985	.04-.06	.051	2.4	<.03-.04	.023	.72	<.03-.04	.030	.61	.02	.02	1.03
24 NOV 1985	************************************ BELOW DETECTION LEVEL ************************************											
3 JAN 1986	<.03-.04	.034	1.1	<.03-.03	.020	.41	.03-.06	.046	.62	<.02-.04	.024	.8
29 JAN 1986	<.03-.03	.026	.42	<.03-.03	.021	.2	<.03-.04	.035	.23	<.03-.04	.035	.44
31 JAN 1986	************************************ BELOW DETECTION LEVEL ************************************											
12 FEB 1986	<.03-.04	.036	1.2	.03-.05	.034	.66	<.03-.-4	.023	.45	.03-.05	.037	1.2
14 FEB 1986	<.03-.07	.047	3.3	.03-.07	.047	1.1	<.03-.06	.043	1.4	<.03-.05	.032	2.4
7 MAR 1986	************* BELOW DETECTION LEVEL ***************						<.02-.03	.023	.43	* BELOW DETECTION LEVEL *		

DUST MARSH MASS LOADING: ZINC

STORM	STATION: K-2 CONCENTRATION (MG/L) RANGE	AVG	LOADING (KG)	STATION: A-2 CONCENTRATION (MG/L) RANGE	AVG	LOADING (KG)	STATION: B-2 CONCENTRATION (MG/L) RANGE	AVG	LOADING (KG)	STATION: C-2 CONCENTRATION (MG/L) RANGE	AVG	LOADING (KG)
12 NOV 1984	.01-.02	.017	1.7	<.01-.02	.009	.38	<.01=.01	.010	.6	<.01-.02	.018	1.8
27 NOV 1984	* BELOW DETECTON LEVEL *			<.01-.02	.010	.25	************* BELOW DETECTION LEVEL **************					
8 FEB 1985	.03-.06	.046	1.8	.02-.08	.046	.1	.02-.05	.040	.13	.02-.08	.032	.093
5 MAR 1985	.01-.11	.085	4	<.01-.03	.009	.29	<.01-.01	.010	.2	<.01-.04	.037	1.9
24 NOV 1985	.05-.13	.102	6.6	.09-.24	.142	5.7	.08-.31	.152	4.1	.04-.2	.119	7.7
3 JAN 1986	.01-.07	.046	1.5	<.01-.04	.010	.21	<.01-.05	.026	.36	<.01-.03	.021	.71
29 JAN 1986	************************************ BELOW DETECTION LEVEL ************************************											
31 JAN 1986	.1-.14	.110	4.4	.06-.13	.115	2.7	.07-.64	.198	3.1	<.01-.13	.049	1.9
12 FEB 1986	.02-.07	.033	1.1	<.01-.04	.021	.42	<.01-.07	.020	.27	* BELOW DETECTION LEVEL *		
14 FEB 1986	.01-.03	.026	1.8	<.01-.03	.017	.39	<.01-.01	.009	.3	<.01-.02	.012	.89
7 MAR 1986	.03-.1	.056	2.6	.02-.03	.027	.75	.03-.04	.035	.66	.01-.03	.019	.86

Table 16. SYSTEM A MASS LOADINGS (KG)

Parameter	Winter 1984-85 Inflow *	Winter 1984-85 Outflow (Sta. A-2)	Winter 1984-85 Percent Change	Winter 1985-86 Inflow *	Winter 1985-86 Outflow (Sta. A-2)	Winter 1985-86 Percent Change
TDS	59,126	116,161	+96	107,400	117,000	+9
TSS	70,291	11,931	-83	18,700	10,900	-42
BOD_5	478	586	+23	642	810	+26
Oil and Grease	83.8	108.9	+30	82.8	110	+33
NH_3–N	67.7	63.5	-6	90	110	+22
NO_3–N	337	152	-55	524	477	-9
Kjeldahl–N (TKN)	369.2	234	-36	352	328	-7
Ortho–P	38.8	8.9	-77	41.2	19.5	-53
Total–P	140.9	36.3	-74	91.8	76.4	-17
Cadmium	-	nd	-	-	nd	-
Chromium	1.49	0.45	-70	9.36	5.65	-40
Copper	0.91	1.32	+45	3.07	2.91	-5
Lead	-	nd	-	1.07	0.75	-30
Manganese	29.9	296.3	+890	38.1	46.5	+22
Nickel	5.76	3.62	-37	3.61	2.37	-34
Zinc	4.5	1.02	-77	10.8	10.2	-6

nd = not detectable; + denotes net increase; – denotes net reduction
* Assumes 60% of Station K-2 flow and loading enters System A

Table 17. SYSTEM B MASS LOADINGS (KG)

Parameter	Winter 1984-85 Inflow *	Winter 1984-85 Outflow (Sta. B-2)	Winter 1984-85 Percent Change	Winter 1985-86 Inflow *	Winter 1985-86 Outflow (Sta. B-2)	Winter 1985-86 Percent Change
TDS	39,417	99,013	+151	71,600	86,000	+20
TSS	46,860	21,024	-55	12,500	9,470	-24
BOD_5	318	540	+70	428	520	+22
Oil and Grease	55.9	106	+90	55.2	67.8	+23
NH_3–N	45.1	52.4	+16	60	43.7	-27
NO_3–N	225	227	+1	350	331	-5
Kjeldahl–N (TKN)	246.2	299	+21	234	309	+32
Ortho–P	25.8	16.2	-37	27.5	22.3	-19
Total–P	93.9	59.1	-37	61.2	88.1	+44
Cadmium	-	nd	-	-	nd	-
Chromium	1.0	0.26	-74	6.24	5.01	-20
Copper	0.60	1.27	+110	2.05	2.25	+10
Lead	-	nd	-	0.71	0.52	-27
Manganese	20.0	34.1	+71	25.4	25.7	+1
Nickel	3.84	3.62	-6	2.41	3.13	+30
Zinc	3.0	0.93	-69	7.2	8.79	+22

nd = not detectable; + denotes net increase; – denotes net reduction
* Assumes 40% of Station K-2 flow and loading enters System B

Table 18. SYSTEM C MASS LOADINGS (KG)

Parameter	Winter 1984-85 Inflow *	Winter 1984-85 Outflow (Sta. C-2)	Winter 1984-85 Percent Change	Winter 1985-86 Inflow *	Winter 1985-86 Outflow (Sta. C-2)	Winter 1985-86 Percent Change
TDS	215,174	282,068	+31	203,000	266,000	+50
TSS	32,955	14,179	-57	20,400	11,300	-45
BOD_5	1126	1428	+27	1,330	1,440	+8
Oil and Grease	214.9	225.1	+5	178	123	-31
NH_3–N	115.9	88.7	-23	154	135	-12
NO_3–N	382.6	326.1	-15	778	743	-8
Kjeldahl–N (TKN)	534.4	452.4	-15	637	748	+17
Ortho–P	25.2	13.8	-45	41.8	30.2	-28
Total–P	95.4	75.3	-21	165	79.9	-51
Cadmium	-	nd	-	-	nd	-
Chromium	0.71	0.90	+27	10.7	5.01	-53
Copper	2.59	2.54	-2	5.16	3.53	-32
Lead	-	nd	-	1.27	0.22	-83
Manganese	330.4	200.7	-39	72.2	133.9	+86
Nickel	7.24	6.49	-10	5.50	4.84	-12
Zinc	1.95	3.79	+94	19.0	12.06	-37

nd = not detectable; + denotes net increase; – denotes net reduction

* Based on Stations A-2 and B-2 loading data from Table 4-2.

Table 19. OVERALL SYSTEM MASS LOADINGS (KG)

Parameter	Winter 1984-85 Inflow (Sta. K-2)	Winter 1984-85 Outflow (Sta. C-2)	Winter 1984-85 Percent Change	Winter 1985-86 Inflow (Sta. K-2)	Winter 1985-86 Outflow (Sta. C-2)	Winter 1985-86 Percent Change
TDS	98,543	282,068	+186	179,000	266,000	+49
TSS	117,151	14,179	-88	31,200	11,300	-64
BOD_5	796	1,428	+79	1,070	1,440	+35
Oil and Grease	139.7	225.1	+61	138	123	-11
NH_3–N	112.8	88.7	-21	150	135	-10
NO_3–N	563.1	326.1	-42	874	743	-15
Kjeldahl–N (TKN)	615.4	452.4	-26	586	748	+28
Ortho–P	64.6	13.8	-79	68.7	30.2	-56
Total–P	234.8	75.3	-247	153	79.9	-48
Cadmium	-	nd	-	-	nd	-
Chromium	2.48	0.90	-64	15.6	5.01	-68
Copper	1.51	2.54	+68	5.12	3.53	-31
Lead	-	nd	-	1.78	0.22	-88
Manganese	49.9	200.7	+302	63.5	133.9	+111
Nickel	9.6	6.49	-32	6.02	4.84	-20
Zinc	7.5	3.79	-50	18.0	12.06	-33

nd = not detectable; + denotes net increase; – denotes net reduction

examination of the groundwater data in Figures 19 to 21 (Section 5 - Groundwater) show a close correlation in water quality between well GW-6 at the west end of System A and wells GW-7 and -8 which, are immediately adjacent to System C but are actually within the Main Marsh. The increase in chlorides and dissolved solids indicates that seepage from the shallow groundwater is a probable determinant in the increase in surface water salinity within the marsh.

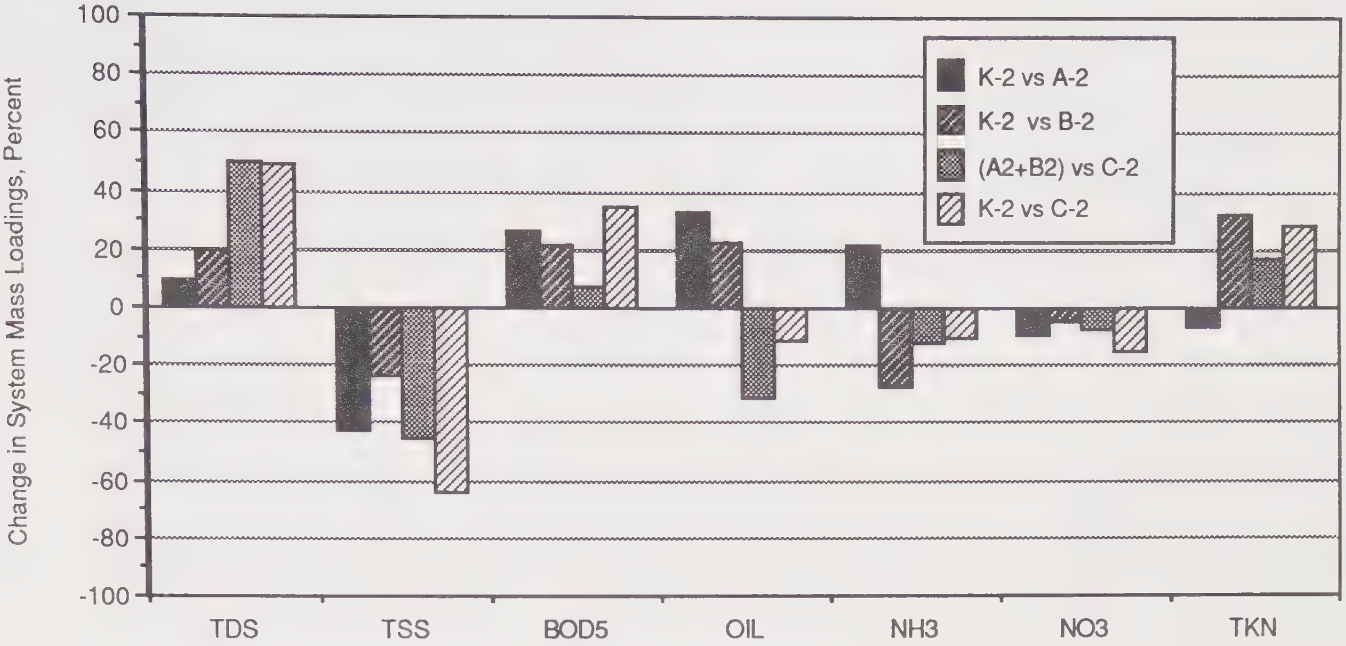
Nutrients

Based on the data presented in Tables 16 through 19 the marsh system significantly absorbed or retained nutrients entering the marsh, with the exception of total Kjeldahl nitrogen, the increase of which is not unexpected. Overall ammonia and nitrate reduction was 10-15%, while phosphate loadings (ortho and total) were reduced significantly, both by approximately 50%.

Within the marsh system, some significant variations in treatment effects are notable. First, a review of wetland treatment systems (Chan et al, 1982) revealed that significant phosphorus reduction occurred primarily in land treatment systems where the water came in contact with a soil interface or soil matrix. System B was designed with a broad overland flow section to maximize the soil-water interface and theoretically effect some level of phosphorus reduction.

Taken at first glance, the data from the DUST Marsh does not support this hypothesis. System A provides significantly better treatment for phosphorus than does System B, reducing ortho-phosphate by 53 percent (compared to 19 percent for System B) and total-P by 17 percent (compared to an increase of 44 percent in System B. However, the earlier studies of phosphorus removal were performed mainly during summer months, when plant growth can be expected to serve as a removal mechanism for nutrients. The DUST Marsh measurements were taken during the winter months when plant growth was slow.

Several factors, such as die-off of aquatic macrophytes (cattail and bulrush) and microphytes (algae), and re-release of deposited organic sediments from bank erosion and pond-bottom scouring,may have contributed to changes in nutrient levels. Seasonal changes in biomass were not measured. However, the durability of cattail and bulrush stems (as evidenced by the large volume of standing dead plant matter present in the spring at Coyote Hills) indicates a slow decay that probably could not cause the observed nutrient levels. Algal growth and decay, on the other hand, could significantly affect nutrient loadings. While chlorophyll 'a' analyses were not conducted in the winter, BOD loadings provide an indication of algal growth. The filtered-water BOD analyses in System A indicate that while suspended solids (including algal cells) decreased 42 percent, dissolved organic matter (BOD), possibly from decaying algal cells, increased 26 percent. An increase of 22 percent in NH_3-N and decreases in all other nutrient parameters indicates the probable dominance of the ammonification process occurring within that system. The suspended solids/BOD relationship does not appear in System B. Increases in organic



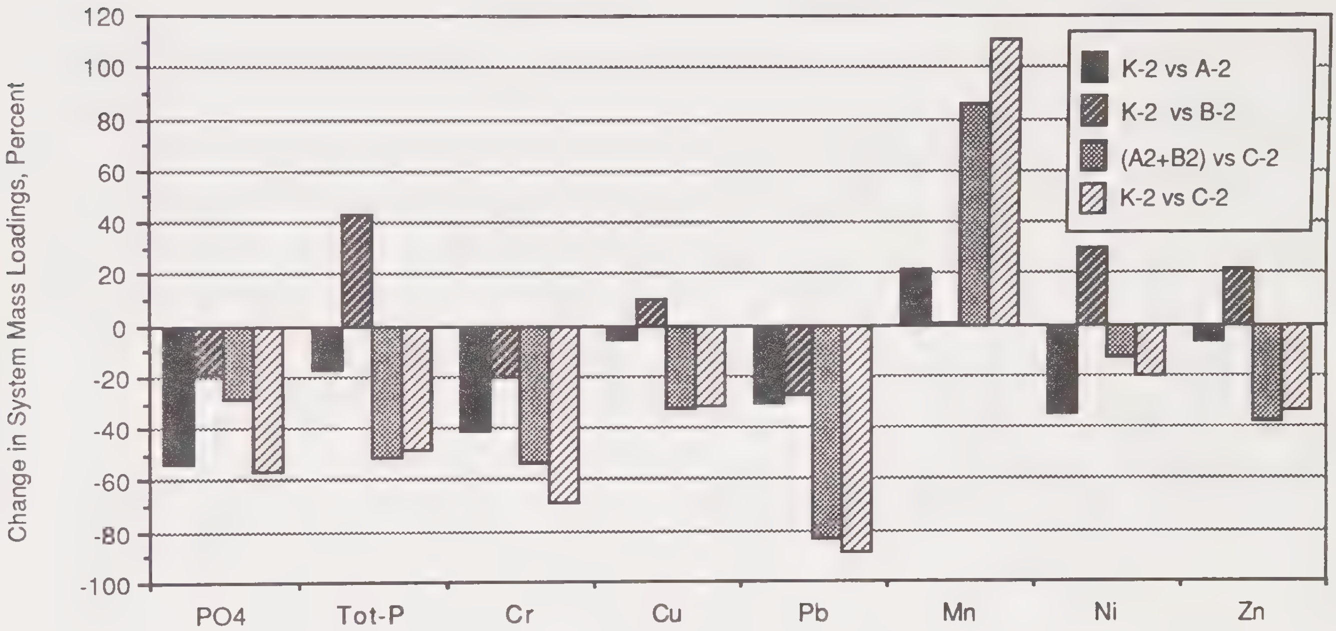


Figure 18. Changes in System Mass Loading Winter 1985-1986

nutrients (Kjeldahl-N, +32%; Total-P, +44%) indicate a source of decaying organic matter within the marsh system other than plant or algal matter. One possible explanation is the remobilization of deposited organic sediments due to bank erosion and pond-bottom scouring. System C exhibits a similar suspended solids/BOD relationship as System A, except that Kjeldahl-N is the only nutrient occurring at a higher loading than the input level (+17%).

Heavy Metals

Heavy metal concentrations, with the exception of manganese and zinc, generally occurred in amounts close to or below the detection limits for the laboratory analysis methods. For the purposes of quantifying mass loadings, the concentration of a non-detectable parameter was assumed to be one unit below the detection limit. For example, if the concentration of nickel in a sample was indeterminate, meaning that it was between zero and 0.03 mg/l (the detection limit), the sample concentration was assigned a value of 0.02 mg/l. With this in mind, the values prescribed for metals in Table 16 and 17 should be considered as order of magnitude estimates only. The reported values include both the dissolved and suspended solid fractions of heavy metals in the water samples.

Heavy metal ions in the water column are typically adsorbed onto suspended particle matter (Chan et al, 1982), and a reduction in suspended solids is indicative of heavy metals removal from the water column. Significant reduction (64%) in suspended solids in the marsh systems lends support to the argument that the DUST Marsh is providing a removal mechanism for heavy metals.

The significant increase in manganese through the marsh system is probably related to the salinity increase phenomenon discussed earlier. While manganese is commonly found in soils, the high manganese levels probably correlate with the intrusion of highly saline groundwater as covered in the salinity discussion.

Suspended Solids, Oil and Grease, BOD

As mentioned earlier, the measured 5-day BOD increase in the marsh system, and within each marsh component, roughly on the order of 20 to 30 percent. The increased BOD may be caused by the resuspension of organic matter from sediments or from algal growth. However, since the measured quantity is only 3-4 mg/l, this increase is thought to be insignificant.

The DUST Marsh did an excellent job of removing suspended solids from the storm water. The highest removal efficiencies occurred in Systems A and C (42 and 45 percent, respectively), though there was a reduction in suspended solids of 24 percent in System B. The overall reduction in suspended solids was 64 percent.

The increase of oil and grease in Systems A and B during Winter 85-86 is difficult to explain. Although there is excellent attenuation in System C (31 percent removal), increases of 33 percent and 23 percent are observed in Systems A and B, respectively. Stenstrom and Silverman (1982) report that oil and grease are primarily associated with particulate matter, and that sedimentation is an appropriate control measure for oil and grease. Given the excellent removal rate of total suspended solids in the marsh, a corresponding decrease in oil and grease would be expected. This appears to occur only in System C. The increases in Systems A and B beyond inflow loadings may be due to the remobilization of deposited oil residues from previous land uses or might be caused by bank erosion and pond-bottom scouring.

Conclusion

Although the level of treatment varied between the individual systems, the DUST Marsh has proven to be an excellent instrument for the removal of water pollutants in urban stormwater. Ammonia-nitrogen and nitrate-nitrogen were reduced 10 to 15 percent; total phosphorus was reduced 50 percent, as was the phosphate component. There was an increase in System B of total phosphorus, and in Systems B and C of Kjeldahl nitrogen, which are probably due to algal decay and remobilization of deposited sediments. Heavy metals were successfully attenuated, except for manganese. The presence of manganese is probably related to the rise in TDS in the system.

SECTION 5
DRY SEASON WATER QUALITY AND GROUNDWATER

DRY SEASON WATER QUALITY

Summaries of the 1984 and 1985 dry season water quality analyses are presented in Tables 20 and 21. Surface water grab samples were collected at each of the wet season water quality monitoring stations during the Summer (August 1984 and June 1985) and Fall (October 1984 and October 1985). The dry season water sampling generally coincided with fish sampling activities and also served as background data for the comparison of heavy metal concentrations in fish.

From an examination of Tables 20 and 21, the parameters that differ most significantly between stormwater and dry season water are electrical conductivity, total dissolved solids, BOD, nitrate-nitrogen, orthophosphate, chromium, copper, manganese and zinc. Of these, electrical conductivity, total suspended solids and BOD show an increasing trend, while the other parameters appear in lower concentrations than stormwater. These changes are caused by groundwater seepage and two phenomena dominant in the summer: high evapotranspiration and high primary productivity.

During the summer, seasonal inflow of surface water is reduced to a trickle. Seepage of groundwater from the shallow water table may occur, but the rates are estimated to be low due to the relatively impermeable clay soils at the site. Water leaves the DUST Marsh system during the dry season primarily through evaporation from open ponds and channels as well as transpiration by vegetation. The average dry season evaporation rate between April 1 and October 30 is 2.9 ft, based on a 31-year record for the Leslie Salt ponds in Newark, 4 mi southeast of the DUST Marsh (Blaney and Mucket, 1955). The average evapotranspiration calculated for a tule/cattail marsh at the same location is 3.7 ft. Since less than one-third of System B is vegetated, the tule/cattail evaporation rate would probably decrease to about 2.7 ft. The DUST Marsh is characterized by large stretches of open water fringed by cattails and bulrush, thus a reasonable estimate of evapotranspiration would be an average of the two rates: (2.9 ft + 2.7 ft)/2 = 2.8 ft/dry season. With an average water elevation of 2.90 ft. at the beginning of the dry season, the minimum water elevation could range from 0.10 to 2.2 ft. Under actual conditions, summer water elevations only drop to 2.87 ft. This indicates that groundwater seepage in the summer is significant enough to offset evapotranspiration losses.

Evaporation, evapotranspiration and seepage of brackish groundwater would contribute to increased dissolved salts and other soluble material in the water. Electrical conductivity and total dissolved solids concentration increased 200 to 300 percent. The amounts of total suspended solids and BOD did not correlate with the salinity increase, but probably varied as a function of increased algal growth (as measured by increased suspended

TABLE 20. 1984 DRY SEASON WATER QUALITY ANALYSES

Parameter	Station K-2		Station A-2		Station B-2		Station C-2		Stn M-1
	8/2/84	10/3/84	8/2/84	10/3/84	8/2/84	10/3/84	8/2/84	10/3/84	10/3/84
pH (pH units)	7.64	7.90	8.51	8.01	8.76	8.15	8.21	7.89	8.43
Electrical Conductivity (micromhos/cm)	4360	4000	3950	5550	4390	5200	4300	6000	8500
Total Dissolved Solids (mg/l)	2780	2500	2700	3600	2700	3200	2820	3700	5400
Total Suspended Solids (mg/l)	<1.0	14	180	190	120	150	120	110	330
5-Day BOD (mg/l)	12	5.2	20	19	18	20	14	15	45
Oil and Grease (mg/l)	-	.52	-	.73	-	.83	-	.53	2.3
Fecal Coliform (MPN/100 ml)	110	540	130	110	920	33	1600	920	>2400
Ammonia-nitrogen (mg/l)	.33	.14	.54	.19	.20	.02	.18	.23	.45
Nitrate-nitrogen (mg/l)	28	7.8	.28	.05	.08	.04	.09	.08	.19
Total Kjeldahl Nitrogen (mg/l)	.64	1.2	3.3	4.0	2.5	4.9	2.3	4.2	12
Ortho-phosphate (mg/l)	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01
Total Phosphorus (mg/l)	<.01	.09	.56	.70	.54	.57	.66	.09	1.6
Chromium (mg/l)	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	.007
Copper (mg/l)	<.02	.02	<.02	<.01	<.01	<.01	<.01	.01	.04
Lead (mg/l)	.004	.01	.04	.01	.01	.01	.006	.01	.02
Manganese (mg/l)	<.02	<.02	.05	.40	.31	.37	.88	<.02	.65
Nickel (mg/l)	<.03	<.03	<.03	.08	.04	<.03	.03	<.03	.10
Zinc (mg/l)	.27	.04	.01	.03	.52	.01	.05	.02	.04

TABLE 21. 1985 DRY SEASON WATER QUALITY ANALYSES

Parameter	Station K-2	Station A-2		Station B-2		Station C-2	
	10/2/85	6/6/85	10/2/85	6/6/85	10/2/85	6/6/85	10/2/85
pH (pH units)	8.54	8.50	8.84	8.50	8.77	8.24	8.60
Electrical Conductivity (micromhos/cm)	2670	3060	3700	3060	4060	2650	3880
Total Dissolved Solids (mg/l)	1600	1800	2100	1800	2200	1800	2300
Total Suspended Solids (mg/l)	36	93	58	120	87	52	39
5-Day BOD (mg/l)	5	9.2	16	12	17	6.5	16
Oil and Grease (mg/l)	2.0	-	.8	-	1.1	-	2.1
Ammonia-nitrogen (mg/l)	.23	.08	.79	.13	.18	.18	.28
Nitrate-nitrogen (mg/l)	.03	<.02	<.02	<.02	<.02	<.02	3.0
Total Kjeldahl Nitrogen (mg/l)	1.7	1.6	3.2	1.5	3.4	1.5	2.1
Ortho-phosphate (mg/l)	.04	<.02	.04	<.02	.08	<.02	.05
Total Phosphorus (mg/l)	.19	.34	.52	.37	.56	.21	.38
Chromium (mg/l)	<.005	.01	.066	.005	.011	<.005	<.005
Copper (mg/l)	<.01	<.01	<.01	<.01	<.01	<.01	<.01
Lead (mg/l)	<.005	<.005	<.005	<.005	<.005	<.005	.006
Manganese (mg/l)	.10	.42	.36	.31	.43	.40	.48
Nickel (mg/l)	.04	-	<.03	-	<.03	-	.04
Zinc (mg/l)	<.01	<.01	<.01	<.01	<.01	.01	<.01
Chlorophyll 'a' (mg/l)	.029	-	.051	-	.21	-	<.01

algal decay (as measured by increased biochemical oxygen demand). Algal assays were performed during Fall 1985. Between the Debris Basin and System B, chlorophyll 'a' levels increased ten-fold.

Fecal coliform levels in 1984 varied considerably and are probably related to areas of wildlife activity. Since fecal coliforms are indicative of wastes from the intestinal tracts of warm-blooded animals, the most likely sources are waterfowl, muskrats, rodents and stray domestic animals.

Nitrate-nitrogen was comparatively lower than stormwater concentrations. Coupled with the increasing chlorophyll 'a' levels, the low nutrient level indicates probable depletion by plants and algae. Ortho-phosphate levels were below the analysis detection limits for all samples, which indicates all available-P was either taken up by primary productivity or bound to the sediments in an insoluble form.

The levels of chromium and copper were nearly always below the detection limit. Manganese and zinc were also significantly less than stormwater concentrations. This is probably due to adsorption onto particulate matter and sedimentation. No significant changes in concentrations of other heavy metals were noted.

GROUNDWATER CONDITIONS

Groundwater conditions in the vicinity of the project site may affect surface water quality and influence maintenance of water levels during the summer. The seasonal height of the water table and proximity to the ground surface may also control the type of vegetation able to colonize the site.

Newark Aquifer

The major aquifer in the local area is the Newark Aquifer. It occurs approximately 20 to 30 feet below the surface and ranges from 80 to 120 feet thick. This pressurized aquifer is important for local agricultural irrigation, although salt water intrusion from the bay and operation of salt evaporating ponds nearby threaten its usefulness. The Alameda County Water District (ACWD) monitors the major aquifers in the Fremont area, and provides general information about the project area. Fall 1981 groundwater monitoring by ACWD indicated chloride levels ranging from freshwater at 144 ppm to 'hypersaline' at 22,300 ppm with an average of 10,000 ppm under the project site. Typical bay water chloride levels approach 15,000 ppm; whereas salt ponds may reach 200,000 to 300,000 ppm.

Lenses of shallow groundwater occur sporadically throughout the Fremont area. These are perched aquifers and generally neither their occurrence nor extent have been measured or recorded. Based on field observations by the ACWD (H. Poustinchi, personal communication), groundwater may be encountered 6 to 12 ft below the surface and range from 2- to 3-ft thick. The shallow groundwater is recharged by percolation from surface runoff and agricultural irrigation, bay water intrusion, and in some areas by percolation from salt evaporation ponds. Salinity in the shallow water

table is similar to bay water, ranging from 15,000 to 25,000 ppm chlorides depending on season and local recharge effects. The flood control channel immediately north of the project site is subject to upstream tidal flows beyond the Newark Blvd. Bridge. Leakage through the flap gates or lateral intrusion from the channel into the water table may account for most of the high salinity value. Extremely high salinities (greater than 15,000 ppm chloride) may indicate intrusion from the salt ponds.

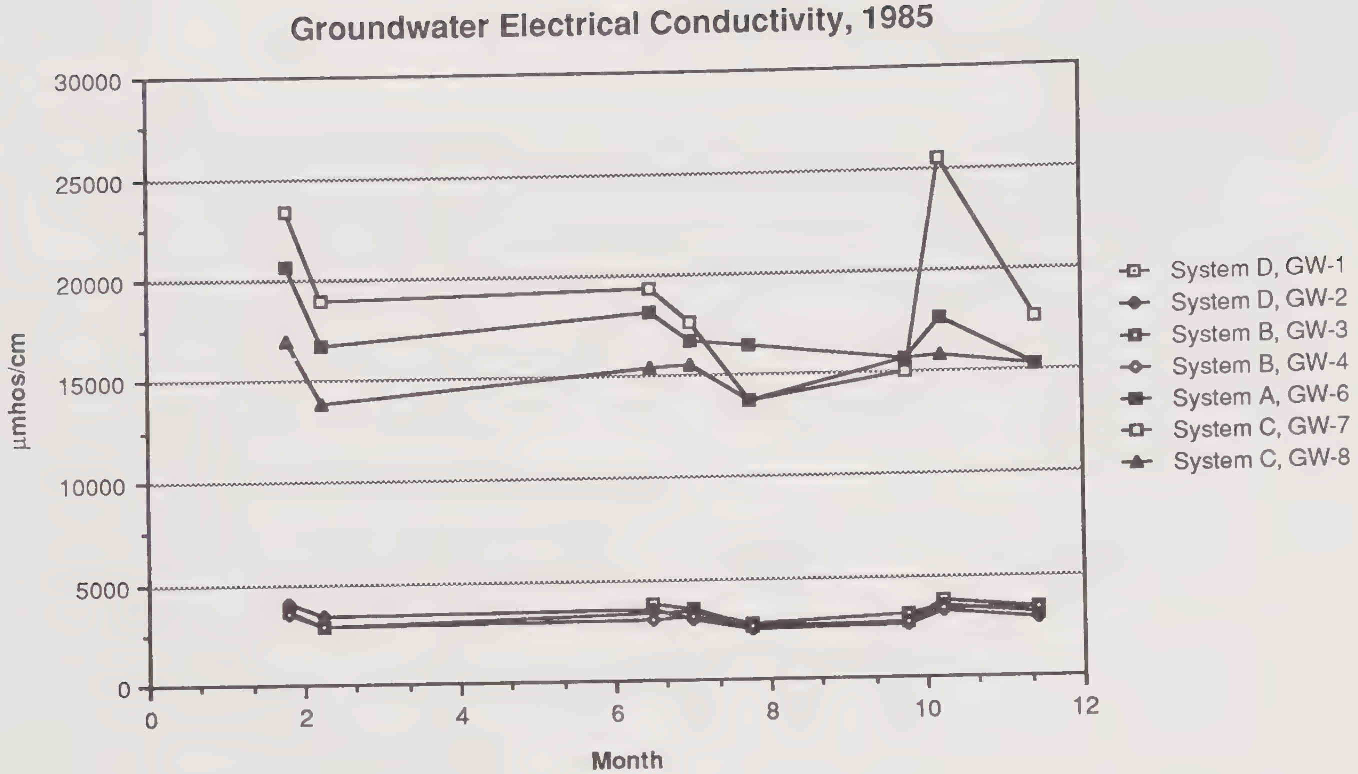
DUST Marsh Groundwater Conditions

Elevation --

The changes in groundwater elevations at the observation wells between February and December 1985 are shown in Figure 19. The ground elevation ranges from 3.5 to 4.5 ft (National Geodetic Vertical Datum). From Figure 19, the water table was observed to be relatively high and close to the ground surface during the winter and spring months. In many instances, the groundwater levels were observed to be higher than adjacent surface water bodies. A gradual elevation trend was also noted from east to west within the study area, as shown in Figure 19.

System D, in the easternmost portion of the study area, was not subject to marsh construction activities and retains the original soil profile. The water table was relatively high -- ranging from 0.8 to 1.3 ft below the ground surface -- and is probably similar to the adjacent agricultural area.

The construction of the overland flow area in System B required the removal of 1 to 2 ft of soil over the 3-acre overland flow area, the deposition of 5 ft of soil on the southern perimeter levee, and the deposition of 1 to 20 ft of soil on the perimeter levee. The finished elevations of the overland flow area were designed to begin at elevation +2.5 ft (NGVD), rise to a +3.0-ft elevation broad transverse mound at the center, and decrease gradually back down to +2.5 ft at the downstream end of the overland flow area. Observation wells GW-3 and GW-4 were installed in the central mound of the overland flow area. During the winter and spring, the 5-ft deep well (GW-3) exhibited water levels 0.17 to 0.39 ft higher than the ground surface; whereas, the 10-ft deep well (GW-4) carried a water level 0.52 to 0.88 ft above the ground surface (see Figure 19). The soils within the overland flow area were comprised of a shallow clay layer (0 to 3 ft) over a thick sand layer, which was highly water permeable. The water table under the overland flow area was confined below the ground surface except at the GW-3 and GW-4 wells where the ground water level rose to the normal height that would have been maintained prior to excavation and construction. The two ponds in System B, which drop to -2.0 ft elevation, are also probably affected by groundwater seepage but to an unknown degree since the sand lenses are interlain between less permeable clay layers.



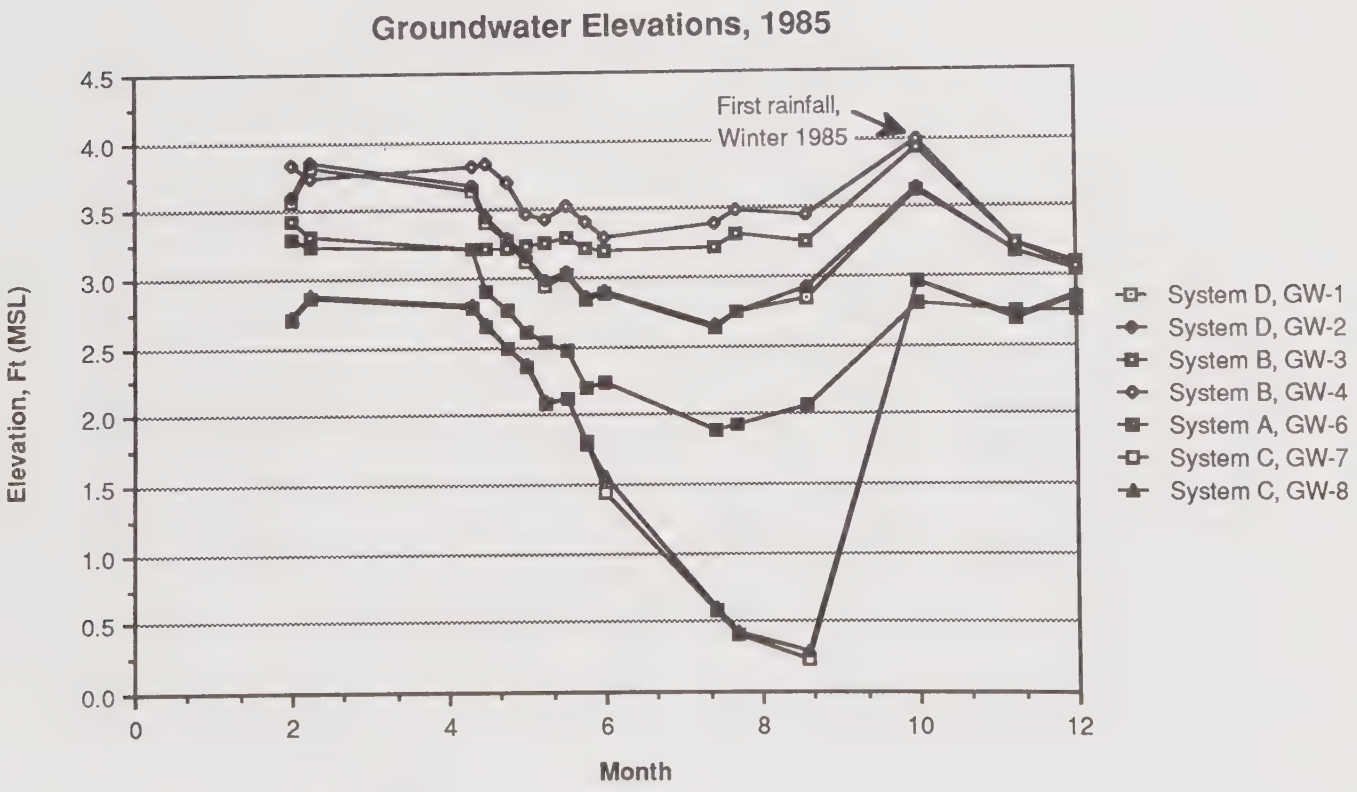


Figure 19. Groundwater Elevations and Electrical Conductivity

Within System A, the old slough channel was widened into a broad lagoon and 1- to 2-ft of spoils were deposited over the remaining 6 acres within the system. The 10-ft observation well in System A was drilled on the western edge where 2 ft of dredge spoils from the widening of the System C channel were placed. The finished ground elevation was +4.15 ft (NGVD). The groundwater level at this location ranged from 0.85 to 3.05 ft below the ground surface. Between System D and System A, the water table had dropped an average of 0.8 ft.

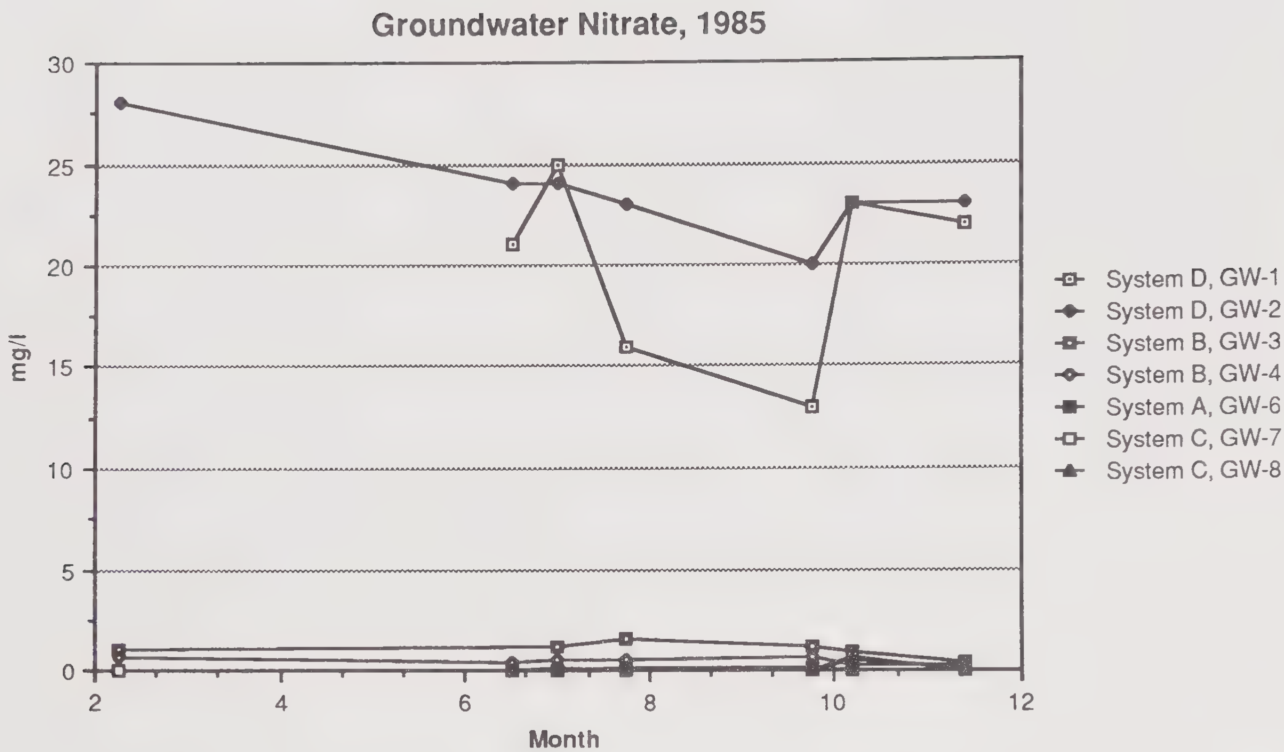
System C and the adjacent wetland area to the south are broad flat areas subject to inundation during the entire winter and spring. The existing System C channel was widened and deepened in various parts, but only minor amounts of dredge spoils were deposited within System C to avoid damage to the wetland habitat. The observation wells for System C are actually 25-30 ft outside of the boundary levee, but the groundwater was judged to be contiguous. The ground elevation was +2.70 ft. Both the 5- and 10-ft wells, GW-7 and GW-8, exhibited water levels at the ground surface or ambient surface water level, whichever was higher. The water level on these two wells decline drastically during the summer (see Figure 19) due probably to overall evaporative stress on the marsh. The water levels were replenished rapidly with the onset of fall rains.

Water Quality --

From the analysis data on Tables 20 and 21, several trends can be observed relating to the continuity of the water table within the DUST Marsh and leaching effects.

The seasonal trend in conductivity levels is shown in Figure 19. This chart, together with the data on TDS, EC and chlorides, show two separate groundwater cells: brackish water under System D and saline water under System C. Under the Salinity discussion in the Stormwater Quality Section, it was noted that the historical occurrence of salt marshes within the Coyote Hills Park Main Marsh and System C area probably accounted for the high salinities observed in System C and extending into parts of System A. Comparisons of the conductivity data between the 5- and 10- ft wells indicate higher salinity in the shallower wells. This accumulation is probably due to seasonal evaporation that tends to concentrate salts in the upper layers.

The seasonal trend in nitrate levels is shown in Figure 20. The occurrence of nitrate-nitrogen corresponded closely with the observed nitrate concentrations in the dry season water quality. In particular, excessively high nitrate levels (14-28 mg/l) were noted in the area adjacent to the agricultural area (GW-1 and GW-2) and low levels in the other systems farther downgradient. Nitrate levels as high as 60 to 90 mg/l under System D during 1981-82 have been observed (Silverman, 1984). As discussed in the Dry Season Water Quality Section, this may be related to agricultural practices in the neighboring field, which involve applications of nitrogen fertilizers.



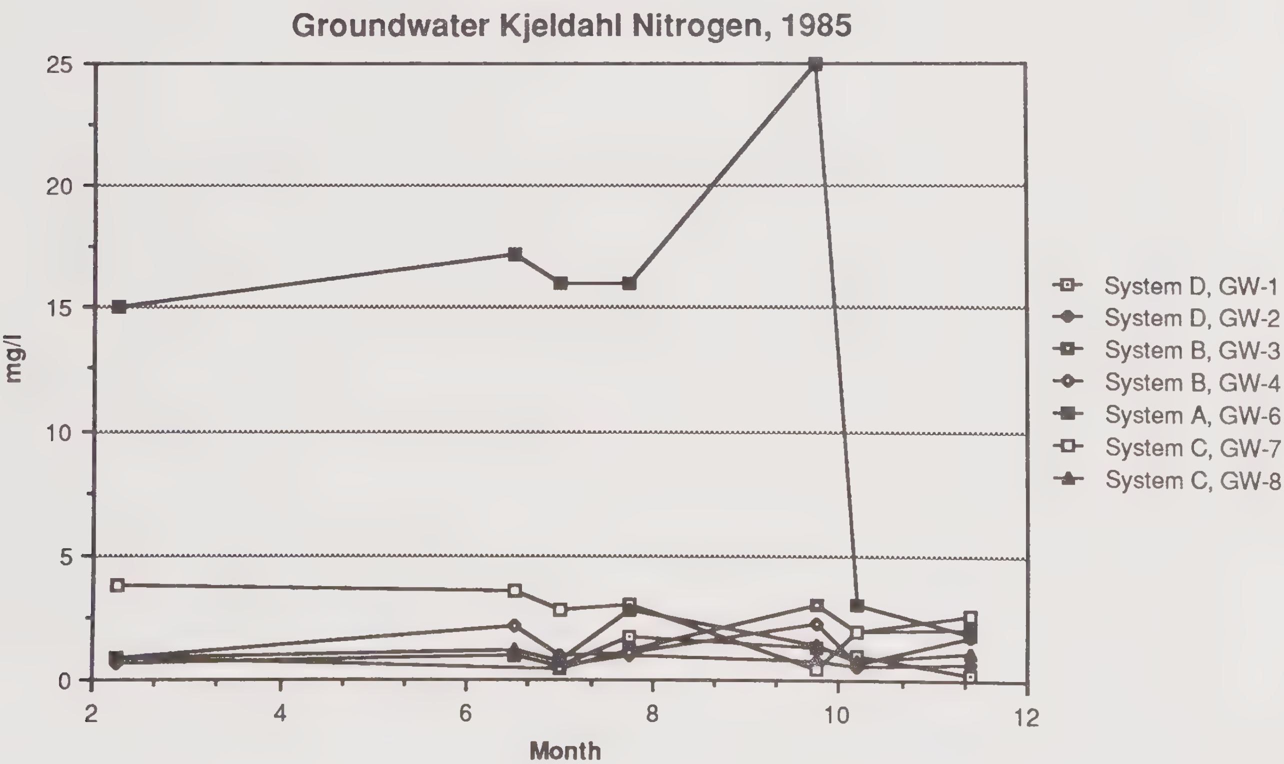
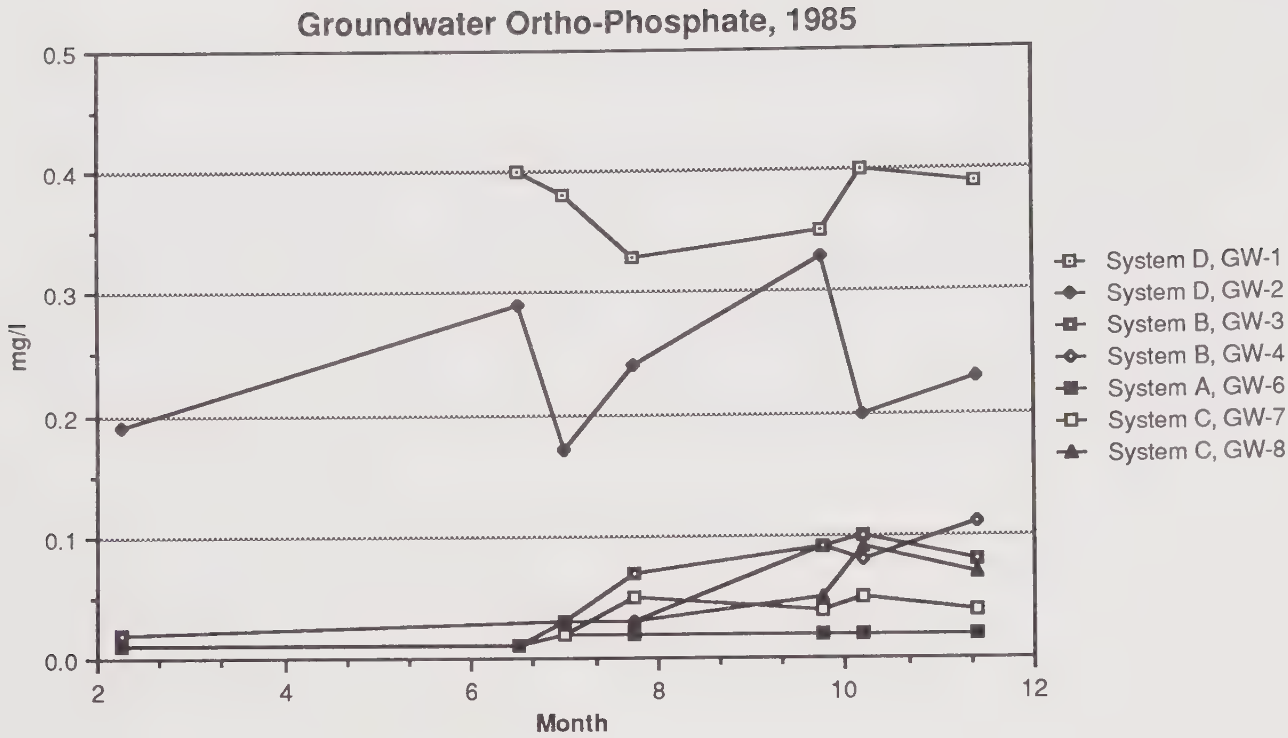


Figure 20. Groundwater Nitrogen

The concentration of Kjeldahl nitrogen levels by well are also shown in Figure 20. The organic nitrogen level was relatively low except in the 5-ft well in System A (GW-3). The extremely high levels in GW-3 (15-25 mg/l), which had little overlying vegetation, are difficult to explain. One explanation is that the well site was formerly covered with heavy pickleweed growth that was buried by 1 to 2 ft of dredge spoils during marsh construction two years earlier. Decay of the pickleweed layer could cause spikes in organic-N levels. Another explanation involves dredge spoils originating from the shallow sediments in the System C channel and containing large amounts of decaying plant matter that could have contributed to the organic-N levels. Another unexplained phenomenon at the System A well was a reddish scum at the water's surface that could have been due to chemical interactions or perhaps microbial activity.

The seasonal trend in phosphorus levels is shown in Figure 21. Orthophosphate levels were generally low with exceptions in System D (GW-1 and Gw-2) of 0.17-0.40 mg/l. This may also be caused by the adjacent agricultural fertilization practices, as discussed under nitrates. Total phosphorus levels, on the other hand, were relatively uniform with a single variance at System B (GW-3), which may indicate contamination.



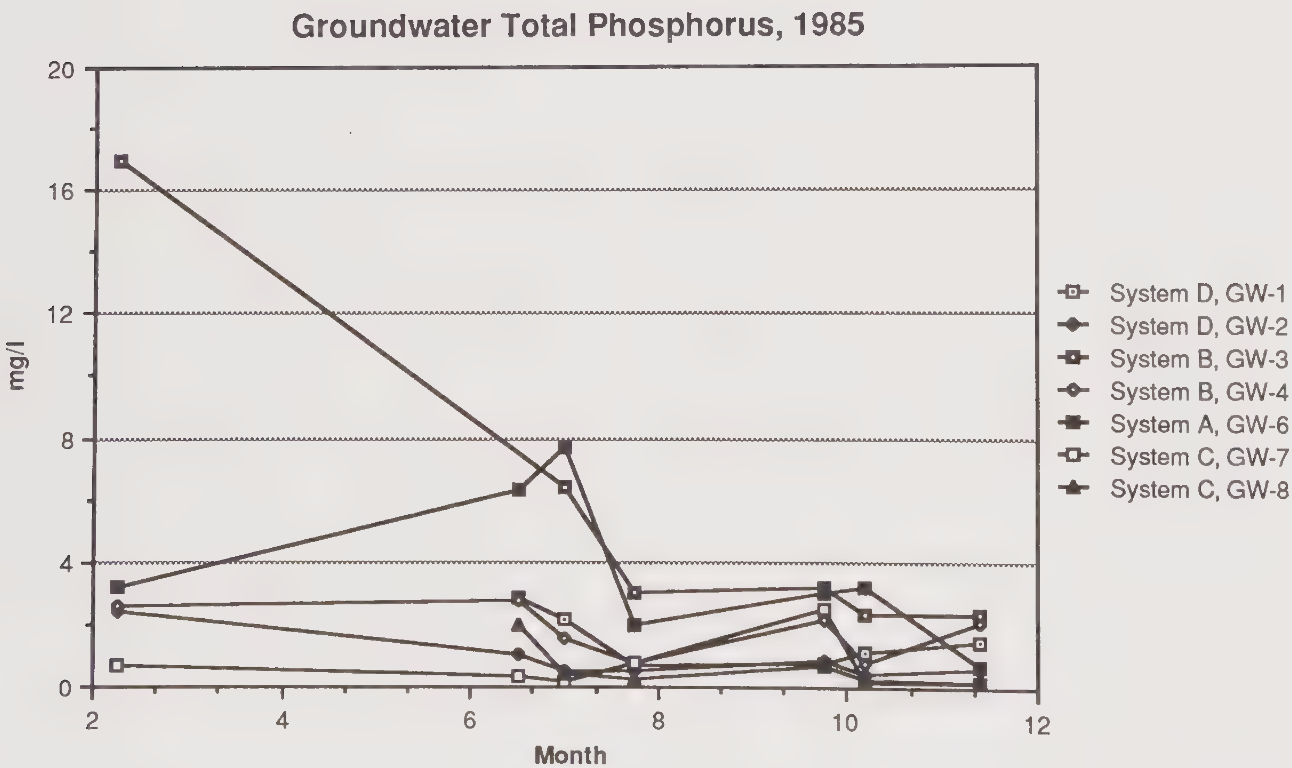


Figure 21. Groundwater Phosphorus

SECTION 6
PLANT COMMUNITIES

VEGETATION

Development of Plant Community on System B Overland Flow Area

Plant species found in the overland flow area during the two vegetation analyses are derived from several different community types -- ranging from freshwater and brackish marsh to upland pioneer types. Vegetation surveys were conducted in Fall 1984 and Spring 1986. No survey was conducted in 1985 because experimental planting activities had disturbed the area. A comparison of the percentage of vegetative cover for the two surveys is shown in Figure 22.

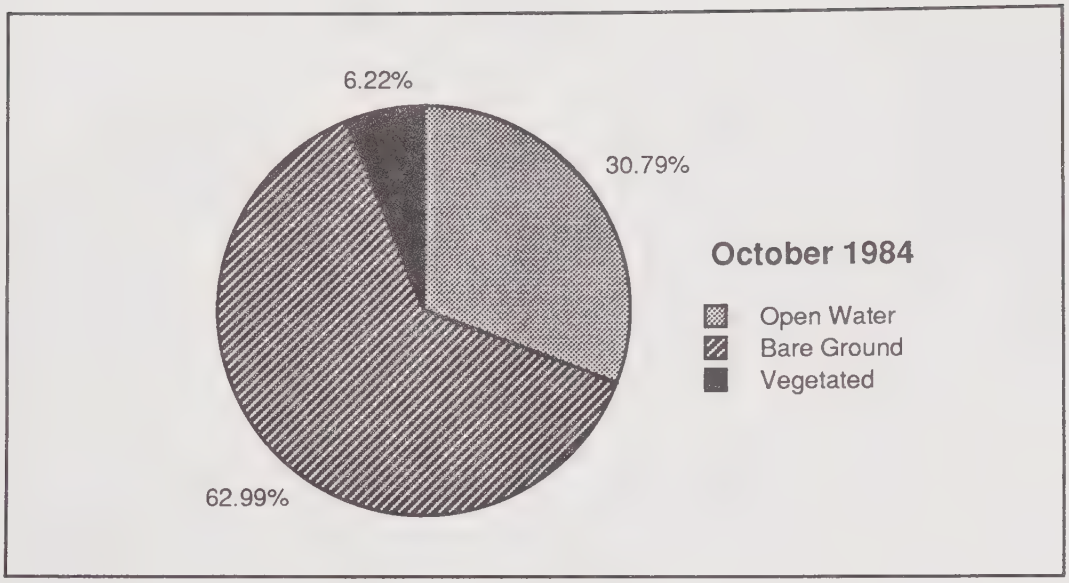
Summaries of the vegetation analyses for 1984 and 1986 are presented in Tables 22 and 23. Plant species are listed in descending order of importance value (sum of relative density, relative dominance and relative frequency). The magnitude of the importance value indicates the relative significance of each plant species within a community. Plant population characteristics, such as numbers, size and distribution, can be inferred by examining the three components of the importance value. Relative density refers to the ranking in number of plants per m^2. Relative frequency denotes the percentage occurrence in all sample plots. Relative dominance refers to the areal coverage of plant species. A comparison of the dominant species is shown in Figure 23.

1984 Survey --

A vegetation survey of the overland flow area was conducted in Fall 1984, one year after Marsh construction. All of the eleven species found in the survey were also present in the K-Line channel and adjacent areas. Most of these plants are pioneer species of disturbed sites and have easily-disseminating seeds that allow for rapid colonization of bare ground. The relative sparseness of vegetation cover after the first year (6.2% of System B or 9.1% of the exposed ground area) probably indicates harsh growing conditions, such as poor soil and limited availability of nutrients. Three of the plant species -- pickleweed, salt grass and fat hen -- are typical of salt marshes and indicate moderate to high salinities occurring in the soil or water. This would be consistent with the historical salt accumulations from irrigation and probable seepage of brackish groundwater into the system. The characteristics of the dominant vegetation in 1984 were:

- Alkali bulrush was the most important or dominant plant in the overland flow area. The high values for density, frequency and dominance indicate many medium-sized plants of even distribution.

- Australian salt bush with a relative density of 11 and a relative frequency of 17 indicated small plants, which were fairly evenly distributed.



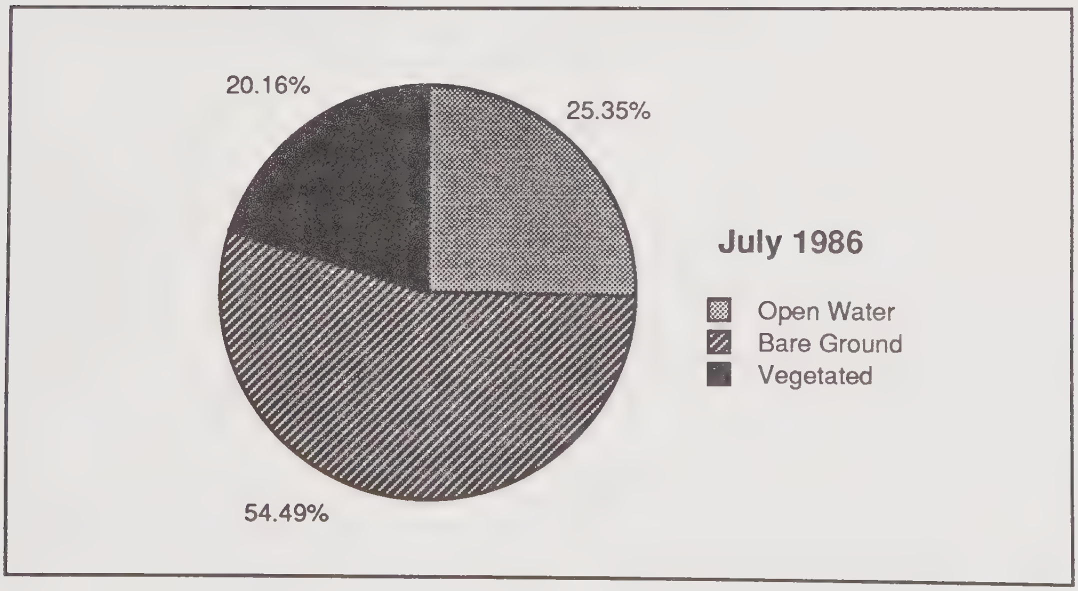


FIGURE 22. SYSTEM B – VEGETATION COVERAGE

TABLE 22. SUMMARY OF VEGETATION ANALYSES
October 25, 1984

Species	Relative Density	Relative Dominance	Relative Frequency	Importance Value*	Percentage
Alkali bulrush (*Scirpus robustus*)	43	31	25	99	33.0
Australian salt bush (*Atriplex semibaccata*)	11	10	17	38	12.6
Ox tongue (*Picris echioides*)	14	3.9	13	30.9	10.0
Birdsfoot trefoil (*Lotus corniculatus*)	5.4	16	8.3	29.7	9.8
Fat hen (*Atriplex patula*)	8.1	4.9	12	25	8.5
Cocklebur (*Xanthium strumarium*)	2.7	17	4.2	23.9	7.9
Marshgrass (*Heleochloa schoenoides*)	2.7	16	4.2	22.9	7.6
Unidentified plant sp. A	5.4	.07	4.2	9.67	3.2
Pickleweed (*Salicornia virginica*)	2.7	1.3	4.2	8.2	2.7
Salt grass (*Distichlis spicata*)	2.7	.40	4.2	7.3	2.4
Goosefoot (*Chenopodiaceae sp.*)	2.7	.16	4.2	7.06	2.3
Total**	100.4	100.73	100.5	301.63	100.0

* Importance Value = Relative Density + Relative Dominance + Relative Frequency

** Totals for relative density, dominance and frequency may not total 100 due to rounding.

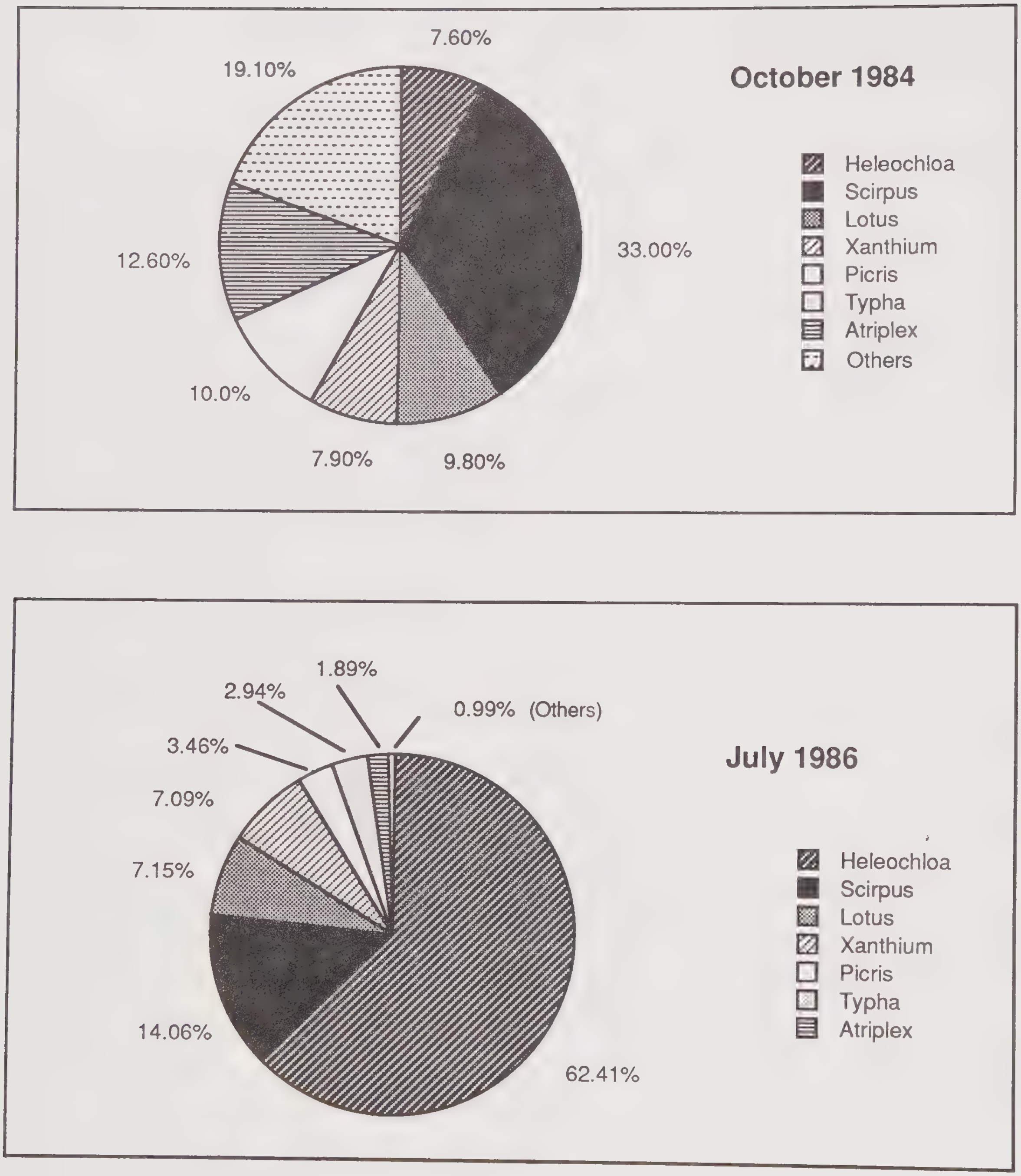


FIGURE 23. SYSTEM B -- PLANT COMPOSITION

TABLE 23. SUMMARY OF VEGETATION ANALYSES
July 9, 1986

Species	Relative Density	Relative Dominance	Relative Frequency	Importance Value*	Percentage
Marshgrass (*Heleochloa schoenoides*)	83.2	42.9	61.2	187.3	62.4
Alkali bulrush (*Scirpus robustus*)	9.6	16.9	15.7	42.2	14.1
Birdsfoot trefoil (*Lotus corniculatus*)	5.4	10.4	5.7	21.5	7.2
Cocklebur (*Xanthium strumarium*)	0.7	16.9	3.7	21.3	7.1
Ox tongue (*Picris echioides*)	0.3	1.3	8.7	10.3	3.4
Narrowleaf cattail (*Typha angustifolia*)	0.5	3.9	4.4	8.8	2.9
Australian salt bush (*Atriplex semibaccata*)	0.1	5.2	0.3	5.6	1.9
Unknown species	0.1	2.6	0.3	3.0	1.0
Total**	99.9	100.1	100.0	300.0	100.0

* Importance Value = Relative Density + Relative Dominance + Relative Frequency

** Totals for relative density, dominance and frequency may not total 100 due to rounding.

- Ox-tongue and fat hen were present as small plants in scattered patches.

- Birdsfoot trefoil with a relative density of 5.4 indicated few plants; a low relative frequency indicated individuals were growing clumped together. However, each plant was fairly large and covered half as much area as alkali bulrush.

Alkali bulrush typically occupies floodplains. These sites tend to be relatively flat with silty soils that experience periodic inundation. Alkali bulrush is a major waterfowl food plant in brackish marshes. It produces large quantities of edible seeds, which are resistant to decay and can persist for several years (George, 1969). According to a report by California Fish and Game (Mall, 1969), bulrush was the major food of an estimated 88 percent of the wintering ducks in Suisun Marsh in the San Francisco Bay estuary. These duck species included pintail, mallard, shoveler and green-winged teal -- all of which have been observed in the DUST Marsh area.

Birdsfoot trefoil grows under a variety of conditions; it is drought-resistant and salt-tolerant. Its relative density and dominance indicated very few but large individuals. Birdsfoot trefoil covered one-half as much area as alkali bulrush, but there were one-eighth as many plants.

Visually, cocklebur was the most conspicuous plant growing 1-2 ft tall. The relative values indicate that plants were infrequent, large and clumped together.

1986 Survey --

Following 1-1/2 years of vegetation development and bulrush planting programs, vegetation cover in the overland flow section had increased to 20.2 percent or 27 percent of the exposed land area. As compared to the density, dominance and frequency characteristics in 1984, species composition and dominance within the System B had changed. Four species were not found in the overland flow area in 1986 -- fat hen, goosefoot, pickleweed, and salt grass. These species are characteristic of moderately saline soils and their absence implies a change to less saline soil conditions. The dominant species in 1986 was marshgrass (Heleochloa schoenoides), a shift from alkali bulrush in 1984. Alkali bulrush ranked as the second most dominant plant.

The characteristics of the dominant vegetation in Spring 1986 were:

- Marshgrass was the most important or dominant plant in the overland flow area. Individual plants ranged from a few inches to 18 inches in diameter. Components of the importance value connote many plants that were widely and evenly distributed.

- Alkali bulrush formed conspicuous stands within the site but did not appear to be increasing in distribution -- as indicated by a

lower value for relative frequency and density in 1986 over 1984. However, a higher value for relative dominance revealed that individuals were larger where bulrush was established.

- Birdsfoot trefoil had less importance in the vegetation of the overland flow area than it did in 1984. Smaller values for relative dominance and relative frequency in 1986 indicated smaller plants clumped together. This species was restricted to the highest zone of the overland flow area where it formed extensive stands.

- Narrowleaf cattail was rare and scattered throughout the site. This was the first occurrence in the center of the overland flow area.

Marshgrass is an introduced annual that is becoming increasingly common in seasonal freshwater wetlands and is valuable forage for waterfowl (Crampton, 1974). Its prostrate habit enables marshgrass to grow and spread rapidly. Prolific seed production by this grass ensures sufficient stock for growth the following year as well as for wildlife food supply.

Narrowleaf cattail formed small, intermittent stands within the center of the overland flow area. These small stands were growing in areas where bulrush was already established. Larger stands were well established on the perimeter of System B especially on the northern edge. Approximate cover by narrowleaf cattail in this area was 33 percent in Spring 1986. This species will probably become a more important vegetation component in the overland flow area within the next 3-5 years.

Coverage-abundance surveys using the Braun-Blanquet method (Mueller-Dombois, 1974) were conducted in selected zones within System B to evaluate the experimental bulrush plantings and conspicuous zones of vegetation not included in the vegetation surveys of the overland flow area. Transects were run through both bulrush planting zones and through the mid-section and northern edge of the overland flow. As shown in Figure 24, approximate areal coverage of bulrush in the experimental planting zones ranged from 2.6 percent (seed-planted area) to 9.8 percent (sprig-planted area). The mid-section of the overland flow area becomes exposed between storms and is the first area to dry out when winter water recedes. Approximate areal cover for bulrush was 18.3 percent. Marshgrass is also present with an approximate coverage of 5.2 percent. Narrowleaf cattail is present in scattered stands and has approximately 2.6 percent cover. The northern edge contains the densest vegetation in the overland flow area. This area is dominated by narrowleaf cattail (approximately 33 percent cover) and alkali bulrush (8.6 percent cover).

Selection of Dominant Plant Species

The newly constructed marsh has several physical characteristics that can affect the rate of vegetation growth and colonization. The primary factors are topography, water flow patterns, salinity concentrations and soil type. During the wet season, the entire overland flow area is subject to periods

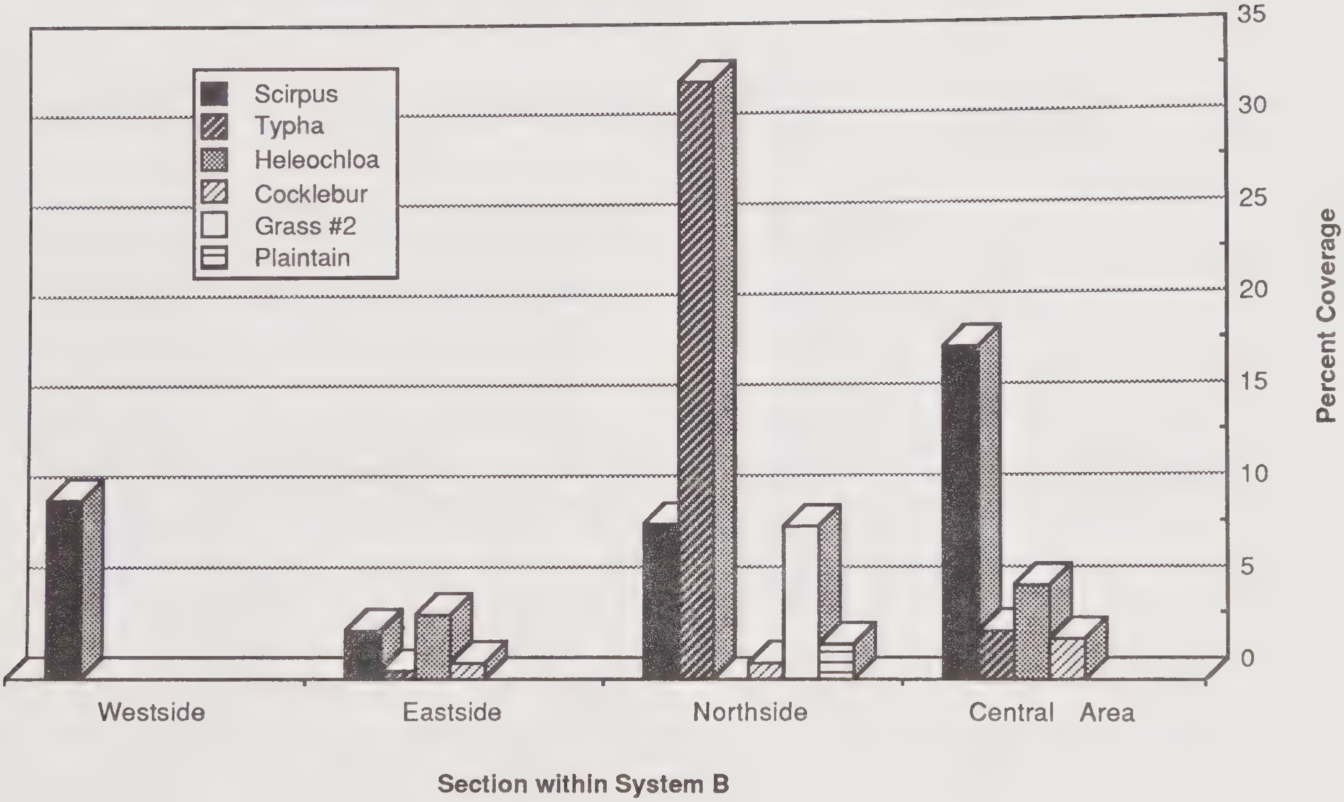


Figure 24. PLANT COVERAGE SURVEY, JULY 1986

of inundation by stormwater runoff. The degree of inundation, soil salinity and water salinity limit plant growth to those species that can tolerate these conditions.

Annual species, such as cocklebur and marshgrass, which tolerate moderate salinity, rapidly colonize marsh soils exposed as the winter water level subsides. These plants mature quickly with high reproductive output and are limited only by excessive salinity. These two species and birdsfoot trefoil are characteristic of floodplain habitats and are expected to remain important components of the highest zone of the overland flow area. Another annual, ox-tongue, grows very densely along the levees adjacent to the marsh, but is unable to invade the marsh itself due to apparent salinity intolerance.

Other annual and perennial species that do tolerate moderate-to-high salinities are subject to competition. The success of one or more species, therefore, is dependent upon adaptation to specific environmental conditions. Listed in Table 24 are five species found on the overland flow area of System B and selected optimum growth requirements (Mall, 1969). Four are among the 11 species listed in Tables 22 and 23 and one (narrowleaf cattail) was observed in close proximity to the area. The requirements for broadleaf cattail, which is dominant in the marsh adjacent to the DUST Marsh, are probably similar to those of narrowleaf cattail.

Salinity requirements for alkali bulrush seed germination range from 0-12 mmhos/cm (Kaushik, 1963). However, salinity levels below 6 mmhos/cm would provide a distinct advantage to the germination of cattail seeds over alkali bulrush seeds.

Soil analysis results in Table 24 show EC (electrical conductivity) values in the upper soil layer of 16 mmhos/cm and decreasing EC with depth. Groundwater conductivity values from Figure 19 (Section 5 - Groundwater) range from .22 to 1.93 mmhos/cm and dry season water salinities (Tables 20 and 21) range from 3.95 to 4.4 mmhos/cm. The salinity levels for all of these soils and water fall within the optimum growth range of alkali bulrush and cattail shown in Table 24.

Based on the environmental parameters defined in Table 24 and some species-specific characteristics, alkali bulrush appears to be the most likely species to dominate most of the overland flow area of System B for the following reasons:

1. optimum growth where the annual depth of flooding reaches 7 to 10 in.,

2. tolerance of longer water inundation periods than other annual species, yet ability to withstand dry periods longer than cattails, and

3. adaptation to brackish and saline soils within the range that occurs in the DUST Marsh,

4. propagation from rhizomes as well as seeds,

5. resistance of seeds to decay and viability for long periods of time (years), and

6. overall hardiness of plant and resistance to disease and pests.

TABLE 24. OPTIMUM FLOODING AND SALINITY REQUIREMENTS FOR SELECTED MARSH PLANT SPECIES*

Species	Mean Annual Depth of Flooding, Inches	Inundation Period, Months	Soil Salinity Range, EC mmhos/cm	Water Salinity Range, EC mmhos/cm
Alkali bulrush (*Scirpus robustus*)	7-10	3-8	3-32	0-25
Fat hen (*Atriplex patula*)	<5	0-5	0-48	4-21
Pickleweed (*Salicornia virginica*)	7-10	0-8	13-52	0-32
Salt grass (*Distichlis spicata*)	<5	0	16-25	1-51
Narrowleaf Cattail (*Typha angustifolia*)	7-10	6-11	2-21	7-8

Reference: Mall 1969

Cattails (*Typha sp.*) are not abundant within the DUST marsh at this time but are expected to continue establishing and expanding their presence. Since cattails require mud flats or very shallow water to germinate, stands already present around the perimeter are most likely the result of germination of wind-borne seeds rather than survival of transplants. Existing plants are found in shallow water and, through colonal growth, will migrate out into deeper water. Cattail and alkali bulrush both require 7 to 10 inches of standing water, but cattail requires 3-5 months longer inundation. It is unlikely that cattail will displace alkali bulrush in the higher sites for the following reasons:

- o bulrush is already becoming dominant within the higher zone of the overland flow forming an impenetrable mat of root and rhizomes;

- o bulrush appears to be better suited to some of the areas within the DUST marsh; and

- bulrush appears to be better suited to some of the areas within the DUST marsh; and

- extensive bulrush stands have been observed in some of the higher zones within the Crandall Creek.

EXPERIMENTAL CATTAIL PLANTING

An experimental planting of 60 cattail plugs on the three submerged berms in System B was conducted. The previous section discussed the favorable characteristics of cattails and the suitable physical and environmental conditions of the berms in the System B. Indications were good for a high success rate. In 1984, 57 percent of the cattail transplants survived for six months. Narrowleaf cattail is present along the perimeter near the area of the experimental plantings, however none of the transplanted cattail survived to 1986. Failure of the experimental plantings was probably due to several factors, including grazing, excessive water depth, and wind and current effects.

Grazing

Animals that feed on the water surface, such as waterfowl, break stems and feed on surface vegetation. Mule deer have also been observed at Coyote Hills grazing near the water's edge and in shallow waters. Muskrats chew off leaves just above the water level for food and nesting material. This type of activity was observed in the marshes adjacent to the DUST Marsh (Collins, 1985) and muskrats have been observed in the DUST Marsh by the research team. Disturbance of the newly planted cattails by bottom-feeding fish, such as carp, could have destroyed newly developing root systems.

Excessive Water Depth

Water depth is one of the more important factors affecting the survival of cattail. Narrowleaf cattail, *T. angustifolia*, is typically 18 percent smaller in overall size than broadleaf cattail, *T. latifolia*. As noted in Section 2 under Experimental Planting, the average water depth on sills 1 and 2, where the broadleaf cattail was planted, is 1.75 ft. The average water depth on sill 3, planted with narrow leaf, is 2.25 ft. The additional depth reduces light transmittance. This factor, in combination with the smaller plant size, could result in decreased photosynthetic activity and growth, and may exceed the tolerance limit of the plant. The water depth on all the sills exceeded the mean annual depth (7 to 10 in.) for optimum competitive ability of *T. angustifolia* (Table 24) and the recommended maximum planting depth of 1.5 ft (Harvey, personal communication). If the newly planted cattail plants established rhizomes, the deterring factors would have been reduced.

Wind and Current Effects

Water depth and physical factors of the DUST Marsh may have contributed to the failure of the cattail plantings. System B was subject to runoff-induced current flows which may have eroded away the disturbed sediments in

which the plugs were planted. With little or no roots to hold the plants in place, the force of the water current could have toppled the new plants. Late afternoon winds, common to Coyote Hills, could also have caused dislodgement and subsequent failure of the cattails. Wind and wind-induced current effects were most pronounced in plants with tall above-water masts that provided greater surface area for interaction. Trimming the tall plant stems to below the water level would have reduced these effects and allowed the roots to stabilize better in the sediment.

SECTION 7
SOIL AND SEDIMENT

SAMPLING RESULTS

Soils within the marsh consist of very poorly drained, fine-textured soils developed in gleyed, highly organic, fine-textured alluvium. Free water occurs at or near the surface resulting in high concentrations of salts. Representative soil characteristics are presented below in Table 25. A summary of mean soil and sediment chemistry as a function of sampling location is presented in Table 26. At Station K-2 (K-Line at Debris Basin), partial cores were taken and analyzed for heavy metals only.

A three-factor analysis of variance comparing the significance of the main effects due to system location depth (soil stratum) and type of vegetative cover is presented in Table 27. Coefficients of correlation and associated probabilities of significance among soil parameters and heavy metal concentrations are shown in Table 28.

ANALYSIS OF SOIL DATA

pH

Figure 25 presents the distribution of pH with depth for the six sampling stations. From Table 27, it is noted that system location represents a significant source of pH variation -- in this case between Systems A and C as compared to the other stations. Depth, however, does not represent a significant source of pH variation.

Stumm et al (1970) noted that the pH of natural waters and sediment is of great significance because pH can determine the direction of chemical reactions and biological processes. From Table 26, it is noted that low pH is correlated with increasing lead and zinc concentrations. Table 27 confirms this trend.

From Figure 25, pH appears noticeably lower under *Typha* plant cover -- between 4.5 and 5.5 under the *Typha* cover. These low pH levels may indicate the deficiency or unavailability of such elements as calcium, magnesium, phosphorus, or the increased solubility and toxicity to vegetation of zinc, manganese or nickel.

TABLE 25
SOIL CHARACTERISTICS,
OMNI SOIL SERIES
COYOTE HILLS MARSH SITE

Characteristics	Depth (inches) 0-6	6-52	52-60+
Texture	silty clay loam	silty clay clay	stratified clay to silty clay
Drainage	poor	poor	poor
pH range,			
series 131*	7.4-8.4	7.9-8.4	7.9-8.4
series 132*	8.5-9.0	8.5-9.0	8.5-9.0
Salinity, mmhos/cm			
series 131*	2	2	2
series 132*	8	8	8
Shrink-swell potential	moderate	high	high
Shear strength	fair	fair	fair
Compactability	good to poor	good to poor	good to poor
Permeability, cm/hr	10^{-3} to 10^{-8}	10^{-6} to 10^{-8}	10^{-6} to 10^{-8}
% silt-clay (<.074 mm)	70 - 90	75 - 95	75 - 95
Liquid limit %	35 - 45	45 - 70	45 - 70
Plasticity index	10 - 20	20 - 45	20 - 40

* Soil Series 131 - Omni drained (Systems A, B and D)
132 - Omni saline (System C)

Soil classifications and descriptions are based on USDA, SCS, Soil Survey of Alameda County - Western part.

TABLE 26. SUMMARY OF SOIL CHEMISTRY DATA 1984-85

Source of Variation	pH** units	EC** mmhos/cm	Chloride** mg/1	CEC meq/100g	Exch-Na meq/m^3	TOC	Particle Size Distrbtn.[a] % sand	% silt	% clay
Location within Marsh									
K-1	7.72	5.90	1720	17	6.1	2800	4.8	67.9	27.3
K-2	—	—	—	—	—	—	—	—	—
System A	6.93	7.99	1660	33	5.8	2600	7.8	33.6	56.4
System B	7.58	4.30	1070	18	3.1	2800	24.5	38.3	36.2
System C	6.98	6.66	1740	33	8.9	8400	4.3	21.5	74.2
Vertical Position									
0 Horizon Surface (0-2")	7.19	7.48	1820	27	6.4	6500	8.8	35.8	55.7
A1 Horizon (2-8")	7.27	7.03	1870	26	6.5	4000	15.3	38.4	49.5
A2 Horizon (8-14")	7.31	4.23	900	24	5.0	3400	12.4	37.4	50.7
Vegetative Cover									
Scirpus robustus	7.43	6.44	1630	24	5.8	4000	13.0	39.4	47.6
Typha latifolia	6.80	5.75	1270	31	6.5	6400	8.2	31.9	59.9

Source of Variation	Ammonia N	Nitrate N	Kjeldahl N	Ortho P	Ttl P	Cd	Cr	Cu	Pb	Mn	Ni	Zn
Location within Marsh												
K-1	4.7	5.2	990	10	430	1.20	110	26	29	29	84	59
K-2	—	—	—	—	—	0.82	140	37	21	880	130	78
System A	4.9	7.0	2100	43	870	0.98	120	36	17	560	120	78
System B	3.2	3.3	950	13	770	1.3	140	32	16	510	110	66
System C	13	10	2300	31	1200	1.1	170	44	45	1300	130	100
Vertical Position												
0 Horizon (0-2")	8.8	7.4	2200	23	870	1.2	140	37	27	800	120	84
A1 Horizon (2-8")	5.6	5.7	1500	27	920	1.1	140	35	31	640	110	76
A2 Horizon (8-14")	5.3	6.4	1300	28	790	0.99	130	35	19	620	120	73
Vegetative Cover												
Scirpus robustus	6.2	6.1	1400	22	800	1.1	130	34	22	620	110	73
Typha latifolia	7.5	7.6	2200	36	1000	1.0	150	40	34	860	130	89

* Mean values mg/kg dry weight except as noted

** analysis of standard saturation paste

a Numbers may not total 100% due to rounding

TABLE 27. THREE-FACTOR ANALYSIS OF VARIANCE, SOIL AND SEDIMENT CHEMISTRY DATA

Independent Variable	F-test for Main Effects[a]			
	Main Effects[b]	System Location	Soil Depth	Plant Cover
pH	0.17	3.74*	0.22	2.93
Electrical Conductivity	0.63	2.31	0.65	0.90
Chloride	0.84	1.19	1.02	1.10
CEC	1.39	10.29**	0.75	0.15
Exchg-Na	0.85	9.98**	0.89	0.02
TOC	4.65**	91.03**	20.00*	6.51
Sand	0.55	8.62*	0.06	0.66
Silt	0.20	2.28	0.18	0.10
Clay	0.42	28.54**	1.06	0.02
Ammonia N	0.75	11.86**	1.27	0.07
Nitrate N	0.85	14.70**	0.19	0.05
Kjeldahl N	2.22	15.50**	6.44**	6.84*
Ortho P	0.20	1.76	0.39	0.55
Total P	0.26	3.63*	0.61	1.72
Cadmium	2.27	2.68	2.07	0.50
Chromium	0.49	5.38*	0.91	1.78
Copper	0.22	4.90*	0.23	1.58
Lead	1.64	5.81**	1.62	2.19
Manganese	0.05	38.36**	1.50	1.11
Nickel	0.46	3.88*	0.49	0.33
Zinc	0.30	17.40**	1.03	3.92

* Significant at $P < .05$

** Significant at $P < .01$

a Degrees of Freedom: Main effects (4, 27); System,Depth (2,27); Cover (1, 27)

b Interaction of location, depth and cover

TABLE 28. SIGNIFICANCE OF LINEAR RELATIONSHIPS* AMONG SOIL PARAMETERS AND HEAVY METAL CONCENTRATIONS

Independent Variable	Cadmium		Chromium		Copper		Lead		Manganese		Nickel		Zinc	
	r	P	r	P	r	P	r	P	r	P	r	P	r	P
pH	.01	NS	-.52	NS	-.47	NS	-.20	NS	-.54	NS	.41	NS	-.58	NS
Electrical Conductivity	.00	NS	.13	NS	.25	NS	.05	NS	.19	NS	.12	NS	.28	NS
Chloride	.00	NS	.16	NS	.17	NS	.06	NS	.13	NS	.09	NS	.21	NS
CEC	-.23	NS	.16	NS	.38	NS	.10	NS	.48	NS	.22	NS	.42	NS
Exchg-Na	.05	NS	.35	NS	.39	NS	.22	NS	.36	NS	.31	NS	.52	<.05
TOC	.15	NS	.72	<.01	.64	<.05	.29	NS	.68	<.05	.61	<.05	.79	<.01
Sand	.22	NS	-.04	NS	-.16	NS	-.23	NS	-.22	NS	.06	NS	.28	NS
Silt	.07	NS	-.38	NS	-.51	NS	.01	NS	-.64	NS	-.62	NS	.44	NS
Clay	-.25	NS	.35	NS	.55	<.05	.19	NS	.74	<.01	.47	NS	.63	<.05
Ammonia-N	.10	NS	.60	<.05	.46	NS	.30	NS	.51	<.05	.45	NS	.64	<.05
Nitrate-N	-.23	NS	.18	NS	.32	NS	.23	NS	.29	NS	.25	NS	.45	NS
Kjeldahl N	.03	NS	.40	NS	.60	<.05	.16	NS	.55	<.05	.46	NS	.71	<.01
Ortho-P	-.55	NS	.28	NS	.14	NS	-.06	NS	.15	NS	-.08	NS	.06	NS
Total P	.05	NS	.53	<.05	.68	<.05	.34	NS	.65	<.05	.66	NS	.64	<.05

* Coefficient of correlation (r) and Probability (P) indicating significance of one-tailed T-test NS=not significant; P<0.05 (95% confidence level); P<0.01 (99% confidence level).

Electrical Conductivity

Soil salinity (as measured by electrical conductivity) distribution as a function of depth is presented in Figure 25. As noted from Table 27, no significant variation was contributed by system location, depth or cover. However, a noticeable trend of relatively higher salinity at the surface layer under the *Scirpus* can be observed in Figure 25. Historical crop irrigation and poor leaching, together with the presence of a high water table and high evaporation rates, all account for soil salinization within the marsh. Variations in soil salinity suggest differential frequencies of recent stormwater inundation and variable depths to groundwater. The occurrence of EC above 4 mmhos/cm indicates saline soils. The presence of birdsfoot trefoil, an annual legume that tolerates soil salinities up to 18 mmhos/cm, also indicates saline soils (U.S. Salinity Lab., 1969). Birdsfoot trefoil is common on the abandoned cropland (future System D) adjacent to System B but does not survive in areas of frequent inundation. In the first year after construction, pickleweed was present in System B indicating high salinities. In subsequent years, with continual winter inundation, the species composition has given way to alkali bulrush and cattail, which are moderately salt tolerant.

Chloride

The variation of chloride ion with depth is presented in Figure 25. As noted from Table 27, no significant variation was contributed by system location, depth or cover. However, as with conductivity, chloride levels appeared to be highest in the upper soil layer under *Scirpus* at K-1 and K-2. One exception is the middle layer in System A under *Typha*. In general, accumulations of this soluble salt were excessively high in all of the soil samples indicating lack of leaching and/or external sources due to seepage, flooding or irrigation water inputs. The high chloride level produces toxic effects on many plants. The colonization of the marsh by salt-tolerant plants such as alkali bulrush and birdsfoot trefoil demonstrates this effect. From Table 28, chloride does not correlate with any heavy metals.

Cation Exchange Capacity

Figure 25 presents the distribution of cation exchange capacity (CEC) with depth for the seven stations. The CEC potential represents the quantity of cations a soil can absorb by cation exchange. From Table 27, it is noted that system location represents a significant source of CEC variation. CEC is dependent upon the amount of clay and organic matter present. The presence of clay -- between 35 and 50 percent with a dominant 2:1 lattice structure -- induces moderate CEC potentials of 36 to 49 meq/100g (Hausenbuiller, 1972). Examination of CEC and clay percentages in Table 26 confirms this effect. CEC is a general measure of soil fertility and physical conditions. Excessively low CEC indicates poor plant growth conditions. CEC correlated positively ($P < .05$) with Kjeldahl nitrogen and ortho-phosphate. From Table 28, CEC does not correlate with observed heavy metal concentrations.

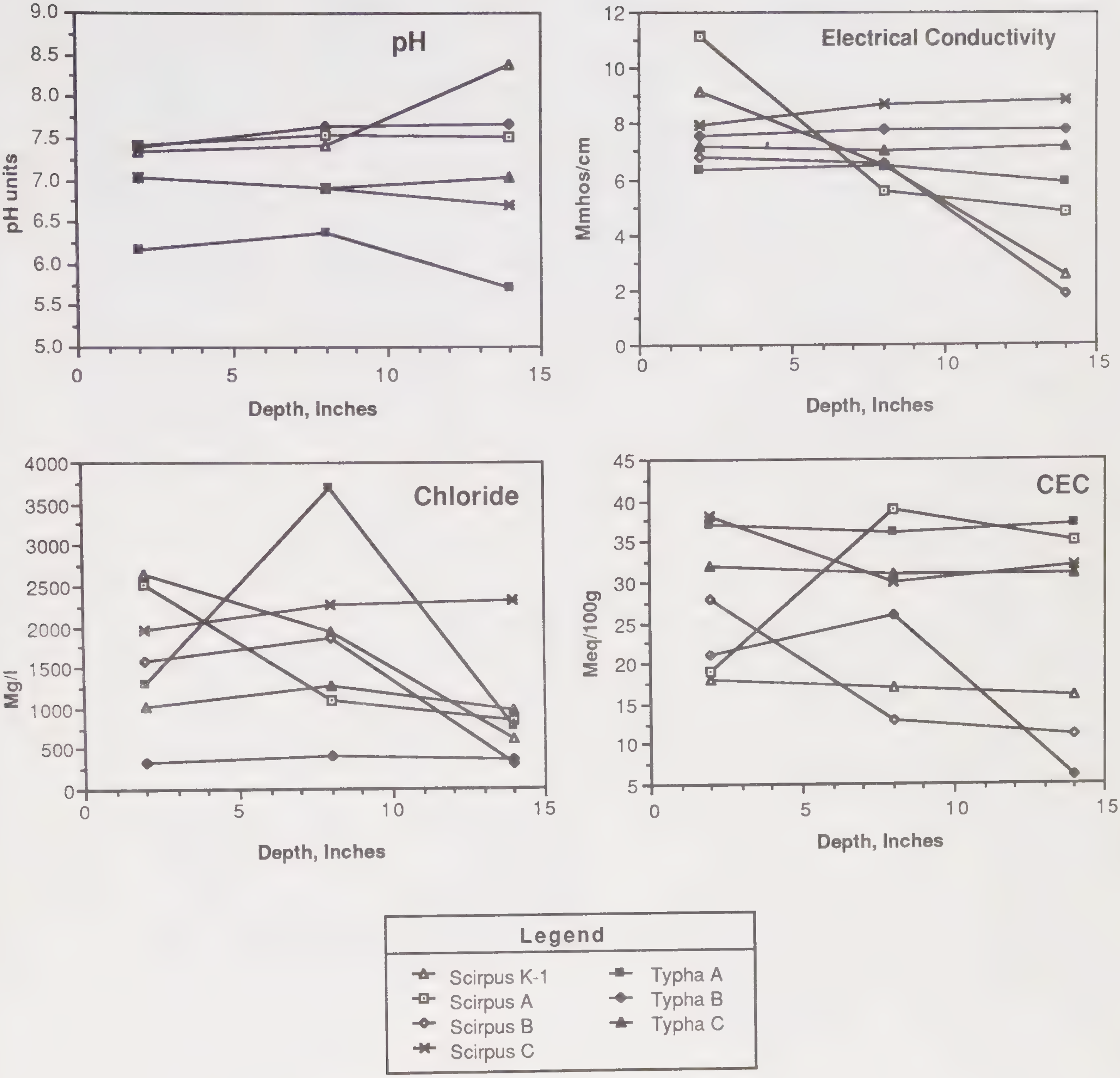


Figure 25. SOIL CHEMISTRY PROFILES

Particle Size Distribution

The cumulative percentages of sand, silt and clay for the three sampling sites are shown in Figure 26. According to Table 27, system location produced a significant variation in sand and clay percentages. Station K-1 contained the highest silt content; whereas System B had the highest proportion of sand and System C - silt. Under the U.S. Department of Agriculture classification system, the System A sites with *Scirpus* and *Typha* cover would fall within the silty clay loam and silty clay categories; whereas the System B site with *Scirpus* cover would be classified as silt loam. The soil texture, particularly the clay component, regulates other physical-chemical properties such as cation exchange capacity and other parameters as shown in Table 29.

TABLE 29. CORRELATION BETWEEN CLAY CONTENT AND SOIL PARAMETERS

Dependent Variable	r	P
Ammonia N	.48	NS
Nitrate N	.52	<.05
Kjeldahl N	.69	<.01
Ortho-P	.51	<.05
Total P	.61	<.05
CEC	.70	<.01
Exchangeable-Na	.51	<.05
TOC	.62	<.05

From Table 28, it is noted that increasing clay content is correlated with copper, manganese and zinc. Adsorption, oxidation and precipitation reactions in an aqueous environment tend to fix the heavy metal ions to fine particulate matter, which form the silt and clay component of the sediments.

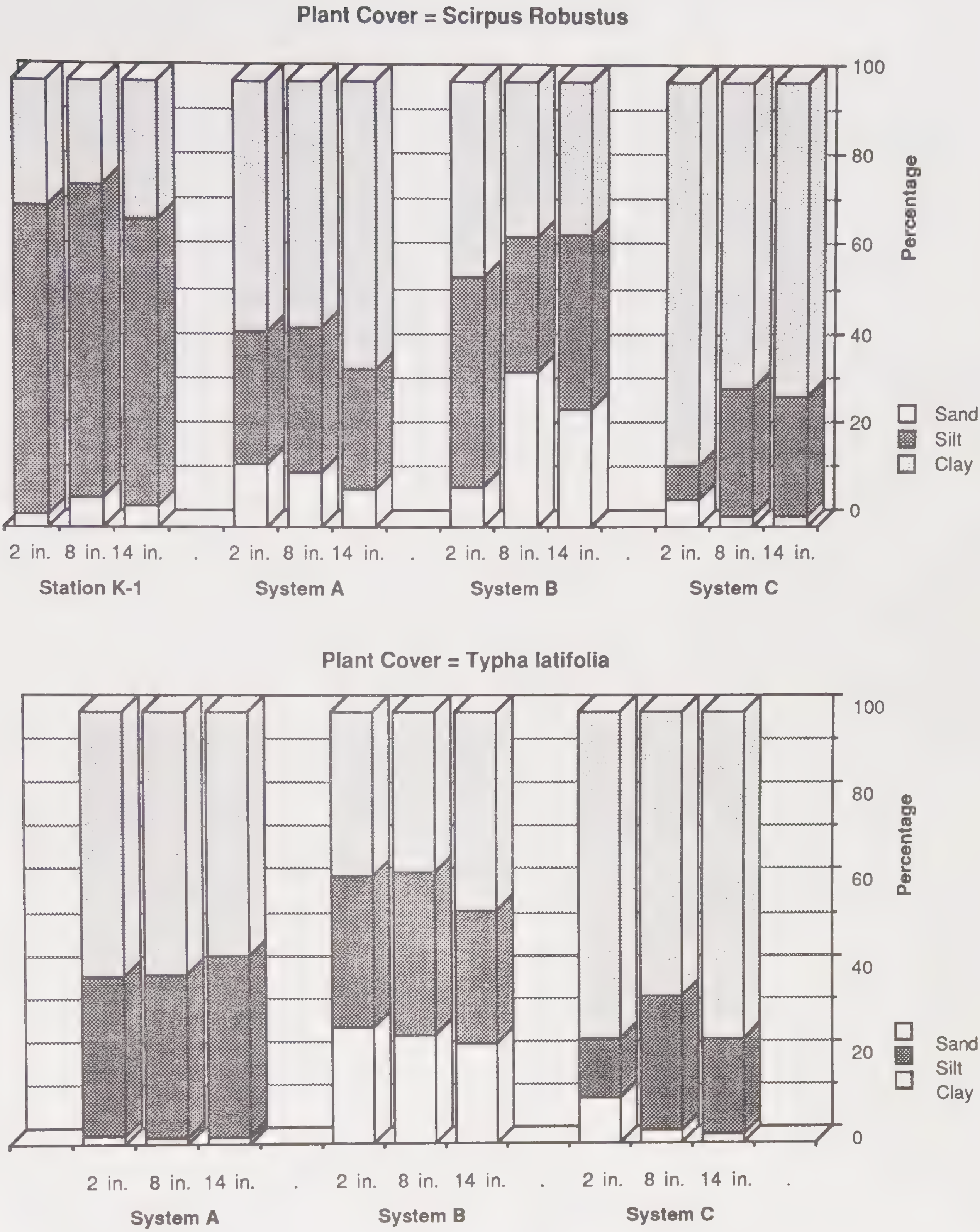


FIGURE 26. SOIL PARTICLE SIZE DISTRIBUTION BY PLANT COVER TYPE

Exchangeable Sodium

The distribution of exchangeable sodium (Na) with depth is shown in Figure 27. Exchangeable-Na is an index of the amount of sodium in the soil-exchange complex. As noted from Table 27, system location presents a significant variation. The ratio of exchangeable-Na over CEC yields percent exchangeable sodium. Within the various soil samples, the percent exchangeable-Na ranged from 16 to 33 percent. Sodic soils are defined as containing more than 15 percent exchangeable-Na (Hausenbuiller, 1972). Excess exchangeable-Na is harmful to plants principally because it induces undesirable effects such as the dispersion of clay. This lowers the permeability of soil to air and water and can result in the formation of dense impenetrable crusts that greatly hinder the emergence of seedlings.

Total Organic Carbon

The distribution of organic carbon as a function of plant cover and depth is shown in Figure 27. From Table 27, TOC correlates strongly with system location, depth and plant cover, and the interaction of these dependent variables as well. From Figure 27, TOC is uniformly low for Scirpus cover in Station K-1, Systems A and B. TOC levels are significantly elevated under Typha in the well-established A and C systems. TOC also correlates strongly with ammonia-nitrogen ($P < .01$); clay content and exchangeable sodium ($P < .05$). Areas with an established protective plant cover retain more organic carbon, which is favorable for the retention of ammonia by exchange adsorption (Hausenbuiller, 1972).

From Table 28, TOC correlates with copper, manganese, nickel and zinc. This is due to the direct correlation between TOC and clay content. The association between clay content and heavy metals was discussed in the section under particle size distribution.

Nitrogen

The distribution of ammonia-nitrogen, nitrate-nitrogen and total Kjeldahl nitrogen (TKN) as a function of depth is presented in Figures 27 and 28. From Table 27 (and confirmed in Table 28), it is observed that location represents a significant source of variation for nitrates and TKN; while system, depth and cover in concert produce significant sources of variation for TKN values. TKN concentrations decrease by depth with mean surface values of 2,200 mg N/kg soil compared to 1500 and 1200 mg-N/kg-soil in the middle and lower depth increment samples respectively. While this may reflect increased input of nitrogenous compounds in the recent past, it may also reflect the translocation of nitrogen from subsurface to surface locations by plant pumping. Nitrogen incorporated into plant leaves and stems by this action is recycled back to the soil surface when the plant biomass dies and falls to the ground.

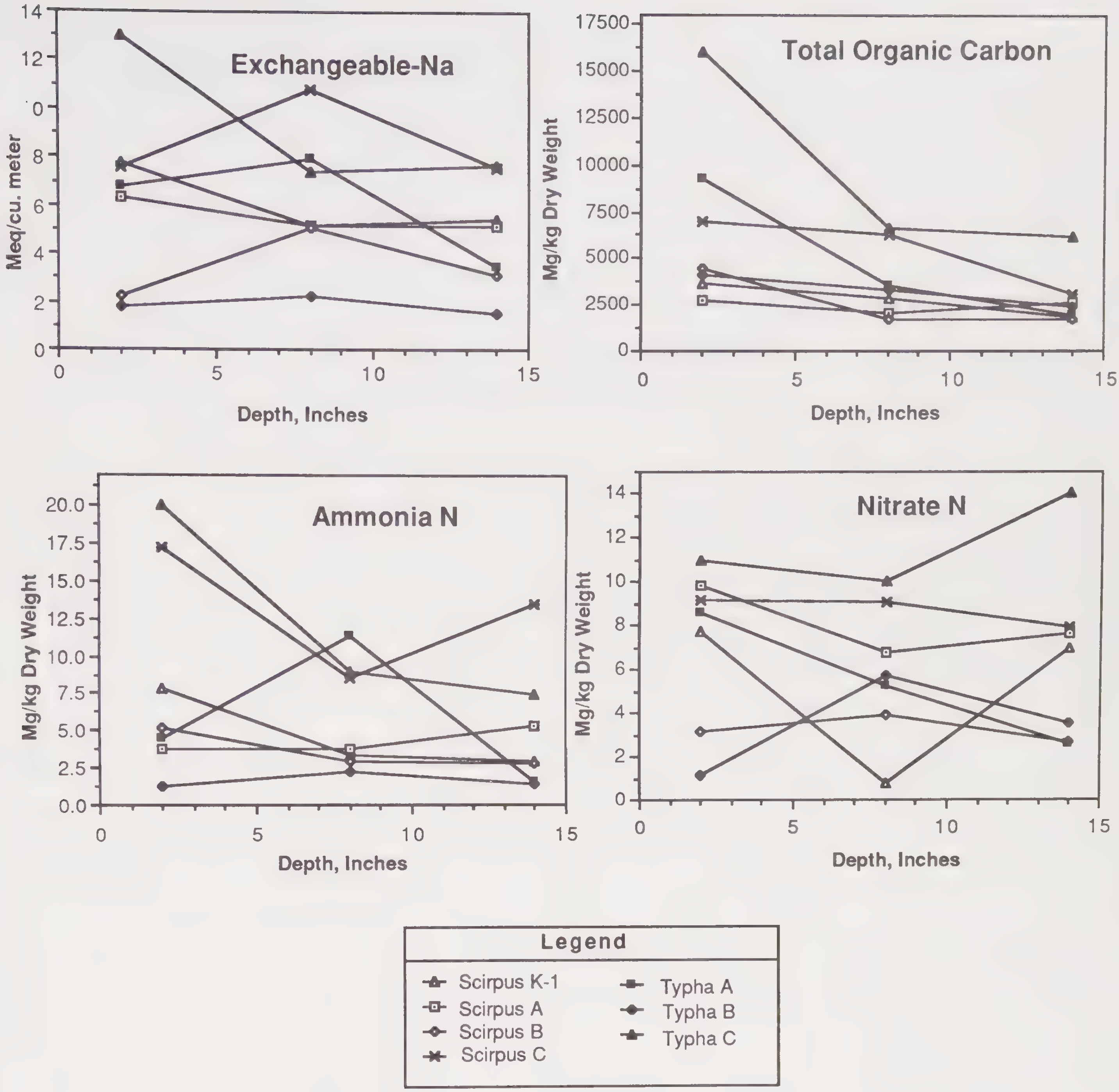


Figure 27. SOIL CHEMISTRY PROFILES

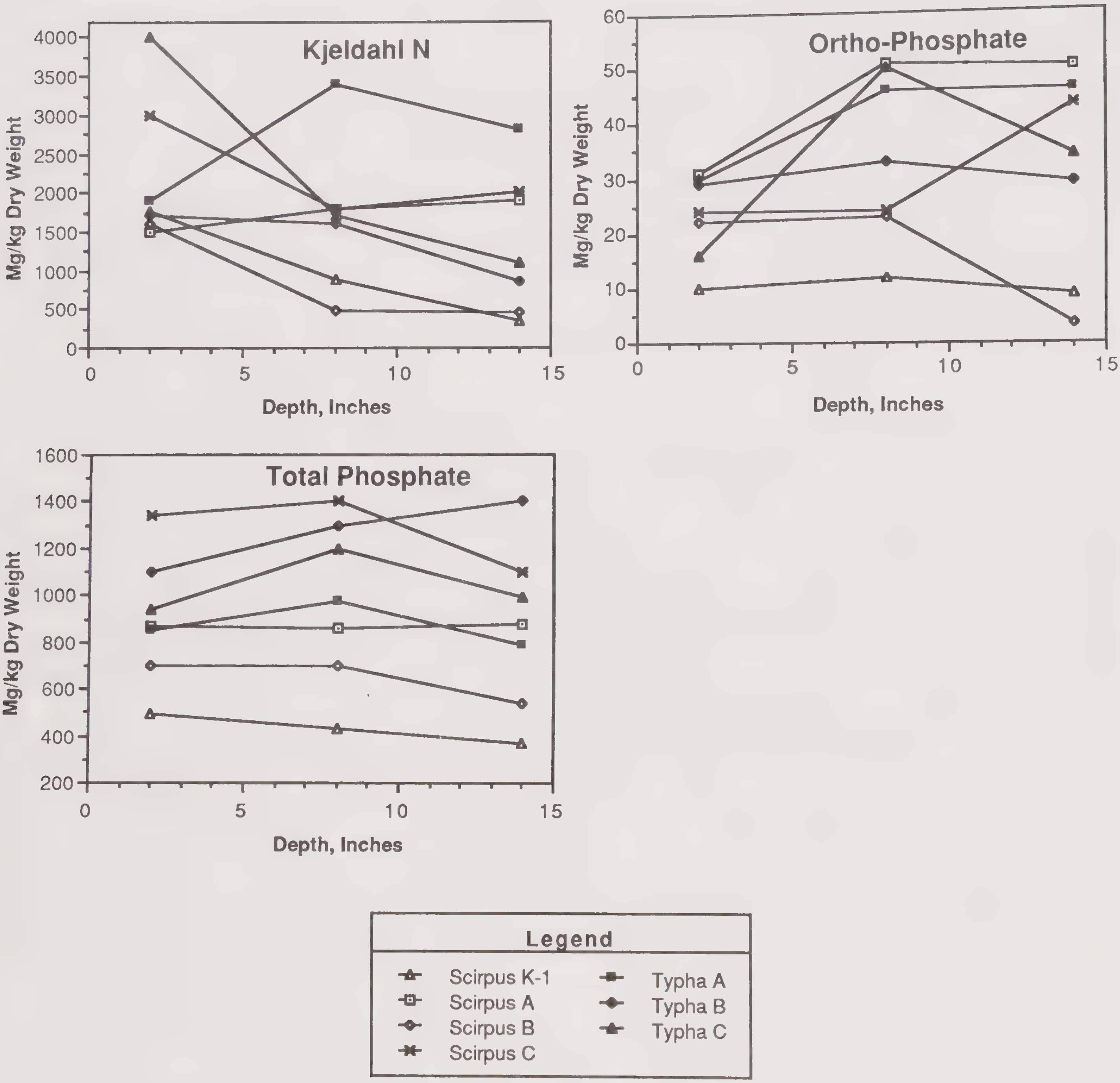


Figure 28. SOIL CHEMISTRY PROFILES

Mean TKN values of 2,100 mg-N/kg-soil in System A and 2,200 mg-N/kg-soil under Typha cover are approximately two times greater than those that exist in System B (950 mg-N/kg-soil) or under Scirpus (400 mg-N/kg-soil). This indicates that significant deposition of nitrogenous compounds is occurring probably through the senescence and breakdown of Typha and other vegetation in System A.

Ammonia-nitrogen generally occurred in low levels in all samples and did not vary significantly with system, depth or cover. The low ammonia levels suggest adequate nitrification occurring in the marsh coupled with ammonia uptake by plant root systems. From Table 28, it is noted that TKN and ammonia correlate with chromium, copper, manganese and zinc. Although organic and ammonia-nitrogen are generally correlated, the relationship between nitrogen and heavy metals have no physical or biochemical basis. The relationship is statistically significant only because of relationships established between these and other variables.

Nitrate-nitrogen occurred in moderate-to-high levels in a majority of the soil samples. However, the nitrate form is the most mobile of all the nitrogen forms, leaching freely through soil layers and readily taken up by plant systems. Thus nitrate levels can vary with the degree of local plant uptake activity. This is particularly important in aquatic systems where high nitrate levels can trigger algal blooms that in turn can rapidly deplete nitrogen from the water. Assessments of algal activity were not conducted on marsh waters; however, the field notes on marsh conditions note the preponderance of green "pea soup" waters with low transparency indicating extensive algal growth.

The high levels of nitrates may be caused by sources other than natural nitrification and soil leaching processes. Immediately upstream of the marsh are heavily-fertilized agricultural fields. Nitrogen inputs to surface and groundwater may be significant from crop runoff. Groundwater within the marsh and immediately adjacent to the crop area exhibited nitrate levels (Figure 19) an order of magnitude higher than marsh locations.

Phosphorus

The distribution of total phosphorus with depth is presented in Figure 28. While total phosphorus is relatively uniform by depth, the levels are significantly higher in System C (Table 27) with a slight trend toward Typha cover (Figure 28). Total phosphorus correlates with clay content ($P < .05$).

The general patterns of ortho-phosphate distribution in Figure 28 are generally similar to those observed for total phosphorus. Although the available-P in System B appears low, available-P is not statistically correlated to system, depth and cover. In general, ortho-P is sparingly available in soils.

From Table 27, it is observed that available-P increases with an increase in total-P, a trend that is to be expected. Additionally, both available- and total-P are correlated with CEC ($P < .05$) -- which increases in soils with high moisture.

Heavy Metals

The vertical distributions of cadmium, chromium, copper, lead, manganese, nickel and zinc are presented in Figures 29 and 30. Though not always statistically significant, certain trends are suggested with respect to heavy metal concentrations. Highest concentrations generally occur in System C. This is most apparent (and statistically significant) for lead and manganese, which are 62 and 57 percent greater, respectively, than either System A and B. The copper and zinc concentrations are relatively high compared to typical soils and other marsh soils such as the Palo Alto Baylands (ABAG, 1979).

The correlation of heavy metals with one another suggests that the mechanism for removal of all the heavy metals are similar. Those locations having characteristics generally favorable for the sorption of one heavy metal would generally be considered favorable for the sorption of others. Locations with fine particle size (high clay content) correlate highly with metal ions. Adsorption, oxidation and precipitation reactions in an aqueous environment tend to fix the heavy metal ions to fine particulate matter. Although ammonia, Kjeldahl N, and total phosphorus are correlated with several heavy metal ions ($P < .05$), there is no physical or biochemical basis for the relationship. These associations are statistically significant only because of the relationships between these nutrient parameters and high clay content.

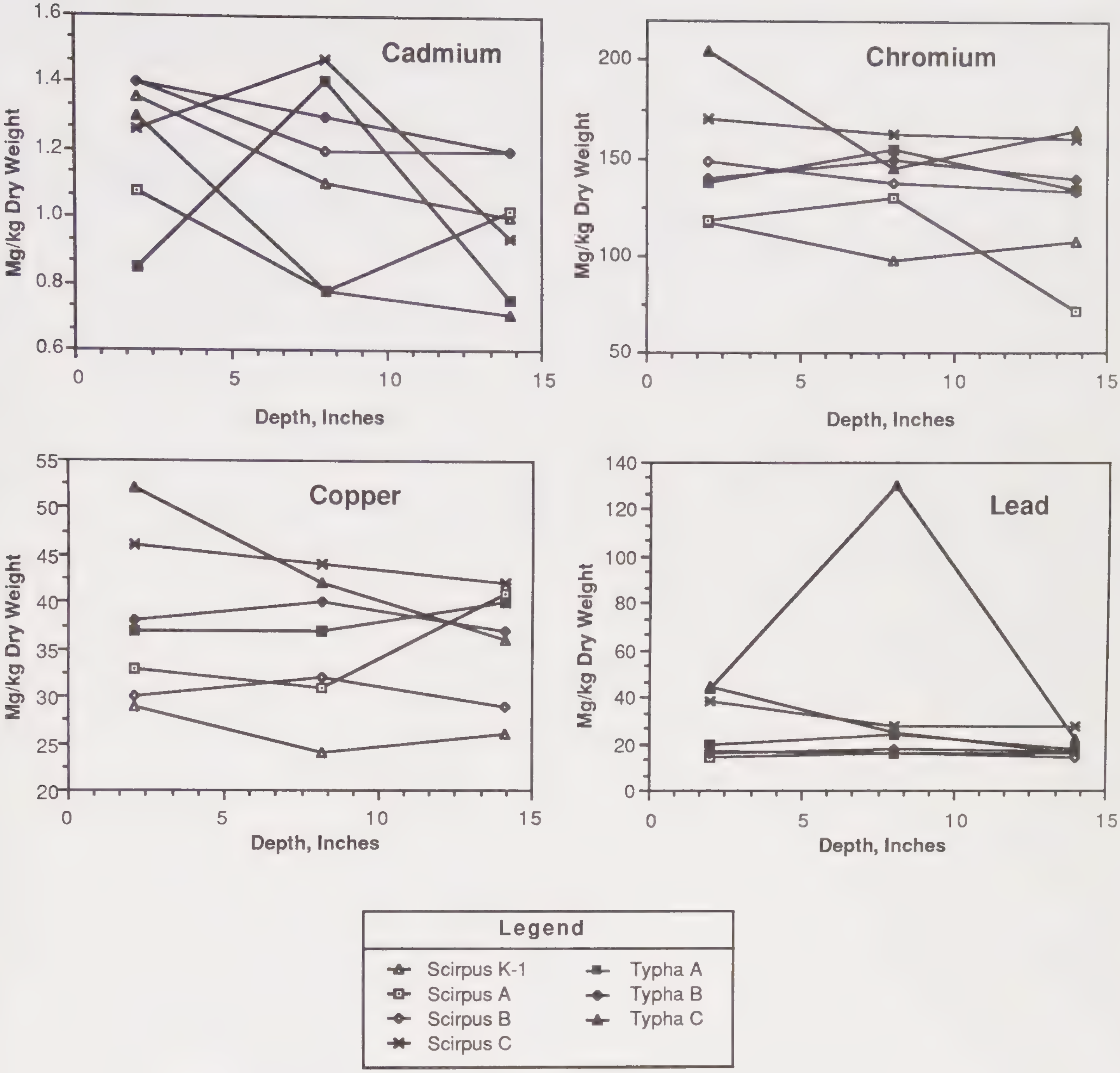


Figure 29. SOIL CHEMISTRY PROFILES

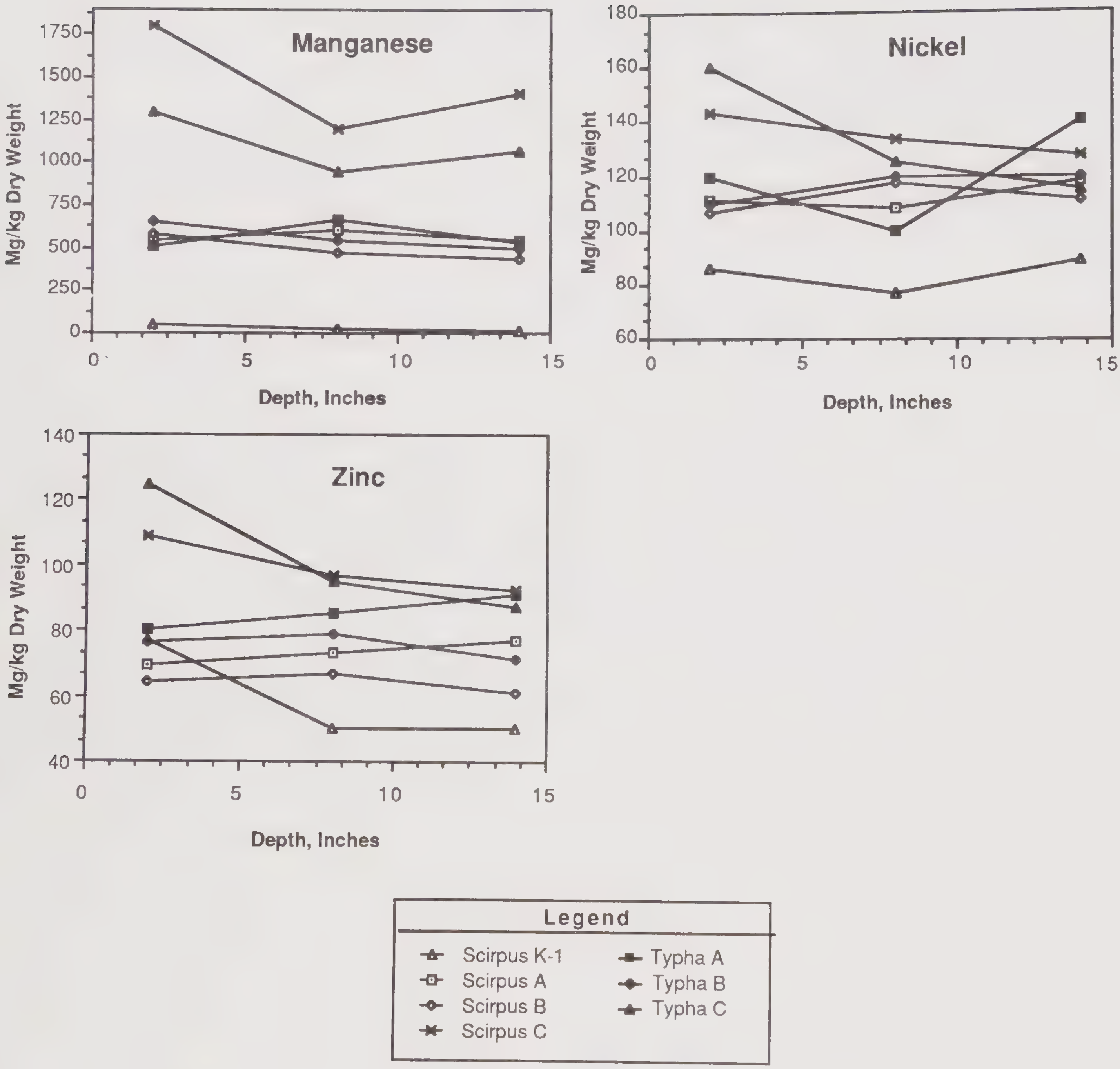


Figure 30. SOIL CHEMISTRY PROFILES

SECTION 8
HEAVY METALS IN VEGETATION

Mechanisms for the removal, translocation and storage of trace metals by wetland ecosystems have been compiled in literature reviews by Chan et al (1982) and Stephenson et al (1980). The studies found that in most vegetative systems, the physiochemical interactions of pollutants and sediments are the primary removal mechanisms. Biochemical interactions are secondary mechanisms for incorporation of trace elements into a system, and can provide additional capacity for pollutant removal in a system (Krenkel, 1975; Boyd, 1970). Increasing the organic content of sediment improves its storage capacity of heavy metals; thus, the natural replenishment of organic material in a wetland aids the physiochemical process (Stowell et al, 1980).

Heavy metals are absorbed by emergent aquatic vegetation primarily via the roots from the sediment, although leaf absorption of heavy metals from water also occurs to a lesser extent. Pollutant concentrations are usually highest in the upper sediment layers, specifically the top few centimeters. Therefore, rooted emergent vegetation, particularly shallow-rooted species and types with creeping rhizomes near the sediment surface, are especially susceptible to heavy metal uptake.

ANALYSIS RESULTS

Tables 30 and 31 present heavy metal concentrations found in various studies for cattails and bulrushes, respectively. The following discussion covers chromium, copper, lead, manganese, nickel and zinc found in cattail and bulrush samples from the DUST Marsh and possible plant/soil heavy metal correlations. No comparisons were made on cadmium, which was below the detection limit in all samples.

A summary of heavy metal concentrations by various plant parts is presented in Table 32. A three-factor analysis of variance comparing the significance of the main effects due to system location, type of plant and plant part is presented in Table 33. The systems under comparison were A, B and C. More than one year's data were available for each of these systems. Plant biomass data are shown on Table 34 and total metal uptake by _Typha_ and _Scirpus_ based on biomass and metal concentrations are presented in Table 35. The uptake amounts were derived from the standing crop at the time of sampling and represent growth over two to three years.

TABLE 30. CATTAIL HEAVY METAL CONCENTRATIONS (PPM, WET WEIGHT) REPORTED IN THE LITERATURE

Plant + Part	Cd	Cr	Cu	Pb	Mn	Ni	Zn	Location & Reference
T. angustifolia	–	–	0.32–98*	–	625–3014	–	12.1–40.4	Ukraine: reservoir
leaves			(2.67)	–	(1997)	–	(24.4)	(Varenko and Chuiko, 1977)
T. latifolia	<1.0	<1.0–4.4	<1.0–4.7	2.6–5.5	–	<1.0–4.7	6.5–17.0	Ontario, Canada: lake
leaves		(1.6)	(1.3)	(3.8)	–	(2.1)	(11.5)	(Mudroch and Capobianco, 1978)
Typha sp	1.5	3.8	19	12	–	28	14	Ontario, Canada:
leaves								polluted lake (Mudroch and Capobianco, 1979)
T. angustifolia								
leaves	<0.5	0.6–3.6	–	–	–	<6–50.6	13.9–39.1	Michigan: eutrophic
roots	<0.5	0.3–1.7	–	–	–	<6–17.6	7.9–33.9	lake (Wells, Kaufman
male flowers	<0.5	2.1–9.0	–	–	–	<6–5.2	27.4–42.7	and Jones, 1980;
fruits	<0.5	2.6–45.2	–	–	–	<6–22.1	24.2–44.1	Estabrook et al,1985)
T. latifolia	<0.5	1.2	–	–	–	<6	21.7	
T. latifolia								
root	–	–	13–265	–	16–901	nd-388**	24–572	Ontario, Canada:
rhizome	–	–	nd-37	–	16–552	nd-80	6–65	wetlands 28 sites
shoot base	–	–	nd-11	–	21–808	nd-24	5–33	1-75 km from
shoot mid	–	–	nd-13	–	46–1314	nd-47	6–68	copper smelter
shoot tip	–	–	3–24	–	127–3080	nd-91	13–101	(Taylor and
fruit	–	–	3–47	–	69–1652	nd-86	22–59	Crowder, 1983)
male flower	–	–	3–34	–	27–972	nd-42	14–34	
pollen	–	–	3–19	–	27–210	nd-31	21–56	
T. latifolia								
leaves	1.34	0.28	–	–	–	2.63	5.59	Charity Is., Lake
roots	1.74	0.78	–	–	–	1.96	4.03	Huron (Estabrook
fruits	0.96	10.89	–	–	–	6.33	16.22	et al, 1985)

* concentrations expressed as range (mean)

** nd = not detectable

TABLE 31. BULRUSH HEAVY METAL CONCENTRATIONS* (PPM, WET WEIGHT) REPORTED IN THE LITERATURE

Plant + Part	Cd	Cr	Cu	Pb	Ni	Zn	Location and Reference
Scirpus sp. leaves	1.0	2.5	15	13	37	51	Ontario, Canada: polluted lake (Mudroch and Capobianco, 1979)
S. fragilis, leaves	<0.5	0.4	–	–	<6	158.5	Michigan: eutrophic lake (Wells, Kaufman & Jones, 1980)
S. acutus, leaves	<0.5-2.9	<0.5-0.8	–	–	<6	19.1-28.8	
S. americanus, leaves	<0.5-7.4	<0.5-2.2	–	–	<6	10.3-37.0	
S. validus, leaves	<0.5	<0.3-1.5	–	–	<6-144.3	28.4-37.0	
S. acutus leaves	<0.5	1.2	–	–	<6	11.0	Michigan: natural lakes (Wells, Kaufman & Jones, 1980)
S. americanus leaves	–	–	–	37.4	–	–	72-hr hydroponic solution 0.5 ppm Pb
leaves	–	–	–	15.9-18.6	–	–	1.0 ppm Pb
leaves	–	–	–	12.4-54.2	–	–	1.5 ppm Pb
rhizome	–	–	–	336	–	–	0.5 ppm Pb
rhizome	–	–	–	345-376	–	–	1.0 ppm Pb
rhizome	–	–	–	542-885	–	–	1.5 ppm Pb
leaves	2.5	–	–	–	–	–	.05 ppm Cd
leaves	4.9	–	–	–	–	–	.10 ppm Cd
leaves	14.1	–	–	–	–	–	.40 ppm Cd
rhizome	26.7	–	–	–	–	–	.05 ppm Cd
rhizome	129.3	–	–	–	–	–	.10 ppm Cd
rhizome	238.7	–	–	–	–	–	.40 ppm Cd
							(Carbonneau and Tremblay, 1972)

* No literature data reported for manganese

TABLE 32. PLANT ANALYSIS SUMMARY*

Marsh System	Plant Species	Plant Part	Cr	Cu	Pb	Mn	Ni	Zn
K-1	Scirpus	Seed	1.9	4.7	4.8	54	nd	25
		Leaf	4.7	5.1	6.7	43	nd	46
		Root	52	19	16	36	nd	81
K-2	Scirpus	Seed	4.6	4.7	3.4	210	5.1	27
		Leaf	3.0	2.6	2.4	503	2.9	6.9
		Root	6.5	5.4	2.7	122	5.1	13
	Typha	Seed	2.1	5.2	3.7	237	3.4	20
		Leaf	2.4	4.2	9.0	803	3.2	26
		Root	15	9.3	6.4	313	12	28
A	Scirpus	Seed	14	9.2	4.4	116	4	20
		Leaf	4.3	7.9	4.4	447	4.5	13
		Root	16	15	9.1	220	22	36
	Typha	Seed	64	5.2	5.4	207	4.1	18
		Leaf	3.3	3.8	6.6	893	4.9	22
		Root	4.8	1.8	9.5	347	43	42
B	Scirpus	Seed	46	8.5	8.3	85	4.3	14
		Leaf	11	10	11.4	330	8.7	8
		Root	12	19	9.2	288	42	30
	Typha	Seed	62	13	4.5	266	5.4	20
		Leaf	10	4.0	17	1200	4	25
		Root	2.5	20	13	460	47	28
C	Scirpus	Seed	2.3	4.3	4.3	283	3.1	14
		Leaf	3.6	3.7	3.5	860	3.9	14
		Root	6.0	8.0	3.4	423	6.4	17
	Typha	Seed	1.9	6.5	5.5	350	4.4	15
		Leaf	1.9	3.0	4.0	447	2.9	11
		Root	7.6	12	6.2	657	7.1	41

* Mg/Kg dry plant weight
** nd = not detectable

TABLE 33. THREE-FACTOR ANALYSIS OF VARIANCE ON PLANT DATA

Dependent Variable	F-test for Main Effects: Joint Effects[a]	System Location	Plant Species	Plant Part
Cr	0.31	0.33	0.49	5.77*
Cu	0.93	1.97	0.25	14.85*
Pb	0.65	8.62*	1.86	2.64
Mn	6.13*	2.81	14.44*	29.37*
Ni	0.25	0.89	0.61	19.55*
Zn	0.63	1.76	3.34	10.96*

a Joint effects of location x species x part
Second and higher order interactions suppressed
Degrees of Freedom: Main effects (2,20); System, Plant (1,21) Part (1,21)
* Significant at $P < 0.01$

TABLE 34. PLANT BIOMASS, SEPTEMBER 1985

Station	Species	Plant Part	Avg Wet Wt, kg/m^2 Mean	Avg Wet Wt, kg/m^2 S.D.	Avg Dry Wt, kg/m^2 Mean	Avg Dry Wt, kg/m^2 S.D.	Percent Moisture
K-2	Scirpus	Root	6.02	3.15	1.53	0.80	0.75
		Leaf	3.96	2.32	1.48	0.87	0.63
		Seed	0.03	0.02	0.004	0.002	0.88
	Typha	Root	10.20	4.39	1.05	0.45	0.90
		Leaf	6.45	1.00	1.35	0.21	0.79
		Seed	0.62	0.35	0.08	0.04	0.87
C-2	Scirpus	Root	18.25	4.80	1.82	0.48	0.90
		Leaf	4.43	0.31	1.04	0.07	0.77
		Seed	0.24	0.03	0.07	0.01	0.71
	Typha	Root	34.65	10.07	2.68	0.78	0.92
		Leaf	13.07	1.17	2.71	0.24	0.79
		Seed	0.81	1.14	1.12	0.02	0.85

TABLE 35. TOTAL METAL UPTAKE BY VEGETATION

Station +Plant Part	Mean Uptake, Mg/m^2*						Total Plant Uptake, Mg/m^2**					
	Cr	Cu	Pb	Mn	Ni	Zn	Cr	Cu	Pb	Mn	Ni	Zn
K-2 Scirpus												
Root	9.94	8.26	4.13	187	7.80	20	14.4	12.12	7.69	932	12.1	30
Leaf	4.44	3.85	3.55	745	4.29	10	(5.19)	(4.31)	(2.16)	(437)	(4.07)	(10)
Seed	0.02	0.02	0.01	1	0.02	0.10						
K-2 Typha												
Root	15.8	6.72	6.72	329	12.6	29	19.16	19.17	19.17	1432	17.19	66
Leaf	3.24	12.2	12.2	1084	4.32	35	(6.77)	(2.89)	(2.89)	(168)	(5.42)	(13)
Seed	0.17	0.29	0.29	19	0.27	1.6						
C-2 Scirpus												
Root	10.9	14.6	6.19	770	11.7	31	14.8	18.70	10.12	1681	15.9	46
Leaf	3.73	3.83	3.63	891	4.04	15	(2.87)	(3.83)	(1.63)	(62)	(3.07)	(8)
Seed	0.16	0.30	0.30	20	0.22	0.98						
C-2 Typha												
Root	20.4	32.2	16.6	938	19.0	110	25.7	41.1	28.1	2226	27	141
Leaf	5.14	8.12	10.8	1210	7.85	30	(5.92)	(9.34)	(4.83)	(273)	(5.53)	(32)
Seed	0.23	0.77	0.65	78	0.52	1.8						

* Mean biomass (from Table 34) x mean metal concentration (from Table 32

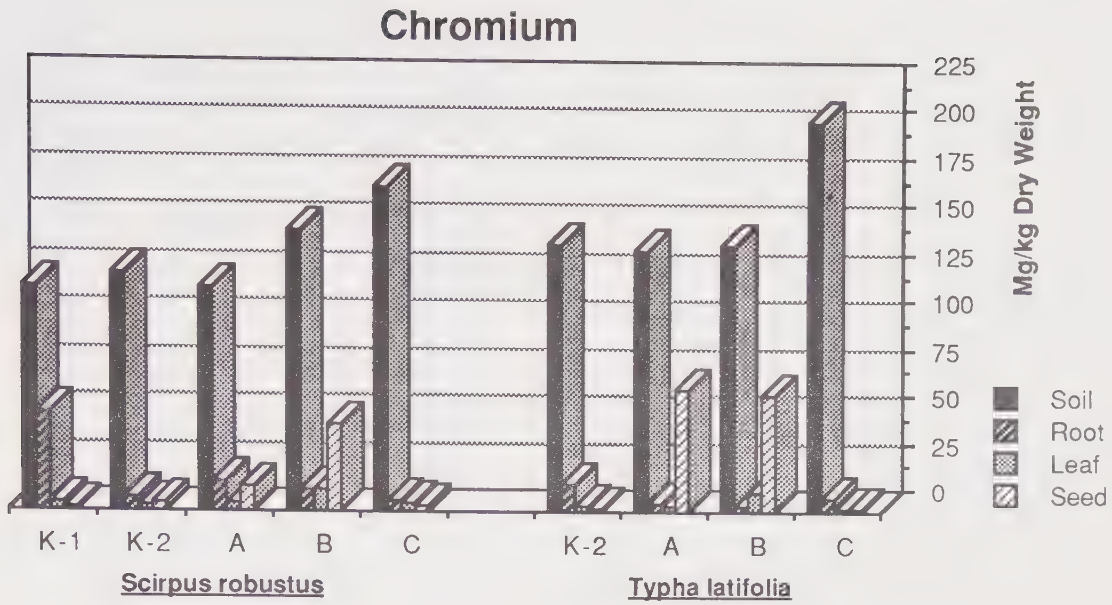
** Sum of root + leaf + seed uptakes, (standard deviation)

Note: Uptake amounts based on standing crop - representing 2-3 years' plant growth

Chromium

The mean chromium concentrations of root, leaf and seed plant parts are compared by plant species and station in Figure 31. The mean chromium concentration in the surface soil layer (0-4 in. depth) associated with each sampling location is also plotted for comparison. Based on the discussion in Section 6 (Soil and Sediment), soluble heavy metal ions are only readily available for plant uptake in the surface soils -- generally within the first few centimeters of depth.

Chromium uptake by Scirpus robustus was generally less than 10 percent of the soil concentration levels. Leaf concentrations of 3.0 to 11.3 mg-Cr/kg -dry plant are higher than the Scirpus levels reported by Wells et al (1980) in Table 31. However, the chromium values in Table 31 were reported from various predominantly freshwater Scirpus species other than the S. robustus found in the DUST Marsh. Root levels range from 5.2 to 15.5 mg-



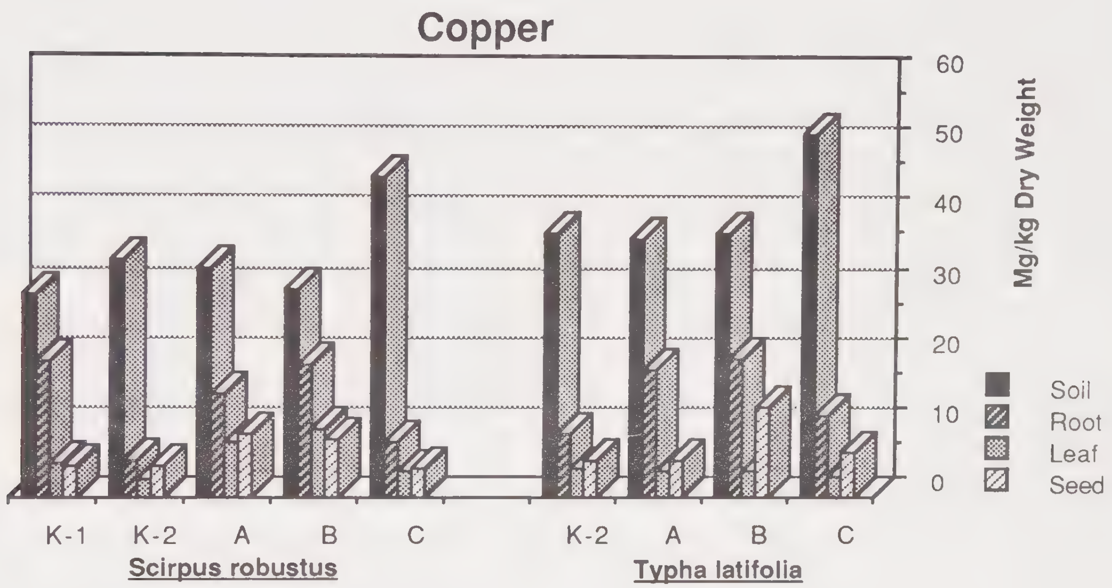


FIGURE 31. CHROMIUM AND COPPER IN VEGETATION

robustus found in the DUST Marsh. Root levels range from 5.2 to 15.5 mg-Cr/kg-dry plant and seed levels range from 1.9 to 45.9 mg-Cr/kg-dry plant. No reported values of Scirpus root and seed concentrations were available for comparison. Total plant uptake of chromium from Table 35 ranged from 14.4 to 14.8 mg/m^2.

Variable uptake by Typha latifolia plant parts was statistically significant as shown in Table 33. Fruit concentrations of 2.1 to 64.8 mg-Cr/kg-dry plant, which in some locations amounted to almost 47 percent of the background soil level, were slightly higher than the Wells et al (1980) reported values of 2.6 to 45.2 mg-Cr/kg-dry plant in T. Angustifolia (Table 30). Leaf concentrations were comparable to reported values, but root/rhizome levels from 2.5 to 14.8 mg-Cr/kg-dry plant were higher than the reported T. angustifolia values. The comparative uptake of other heavy metal ions by Typha roots in this study indicates that chromium root levels are within average bioaccumulation ranges. Due to the greater overall biomass associated with Typha, total plant uptake ranged from 19.2 to 25.7 mg/m^2 -- nearly 80 percent greater than Scirpus.

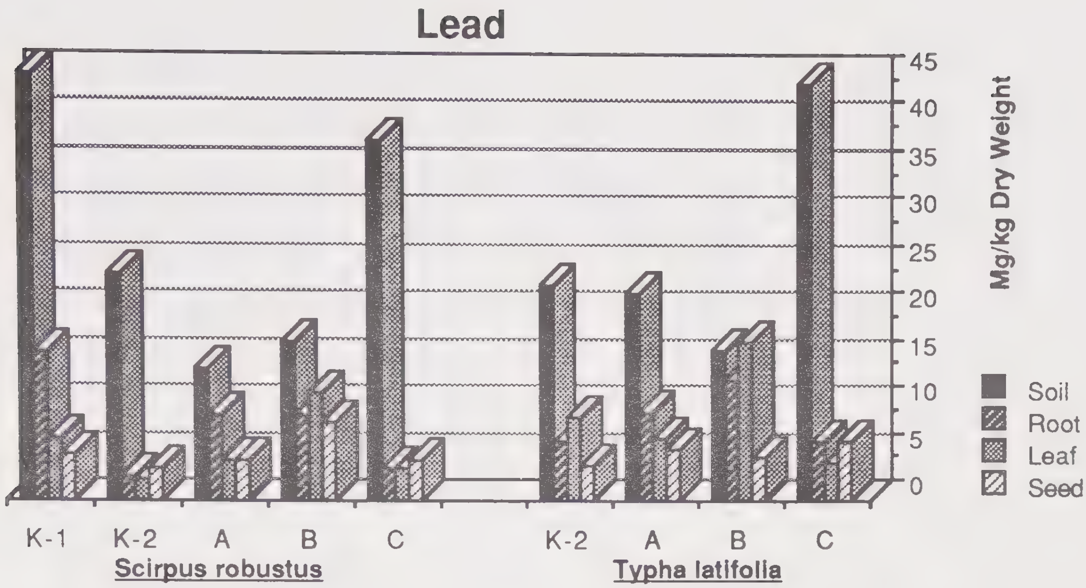
Copper

The mean copper concentrations of root, leaf and seed plant parts are compared by plant species and station in Figure 31 from Table 33, plant part -- specifically roots and tubers -- accounted for the major source of variation. Root copper concentrations in Scirpus ranged from 5.4 to 19.3 mg-Cr/kg-dry plant. There were no seed and root values reported in the literature for comparison. Total plant uptake of copper ranged from 12.1 to 18.7 mg/m^2.

Typha root levels ranged from 12 to 20 mg-Cu/kg-dry plant, leaf values ranged from 3 to 4.2 mg-Cr/kg-dry plant; and fruit levels ranged from 1.3 to 6.5 mg-Cu/kg-dry plant. These concentrations compare favorably with the control stations analyzed by Taylor and Crowder (1983) in a study of 28 sites in the vicinity of a copper smelter. Typha root/rhizome tissue typically took up 23 to 50 percent of the soil copper concentration levels in the DUST Marsh. Due to the greater biomass and uptake rates in Typha, total plant uptake ranged from 19.2 to 41.1 mg/m^2 -- more than 3 times greater than Scirpus.

Lead

The relative concentrations of lead occurring in the various plant parts by species and locations are shown in Figure 32. From the analysis of variance in Table 33, system location rather than plant part represents the most significant source of variation. Lead occurrences for both plant study species are relatively higher in System B. Since background soil lead levels are comparable in the K-2, A and B systems, the actual plant specimens appear to be the source of variability. The overland flow area



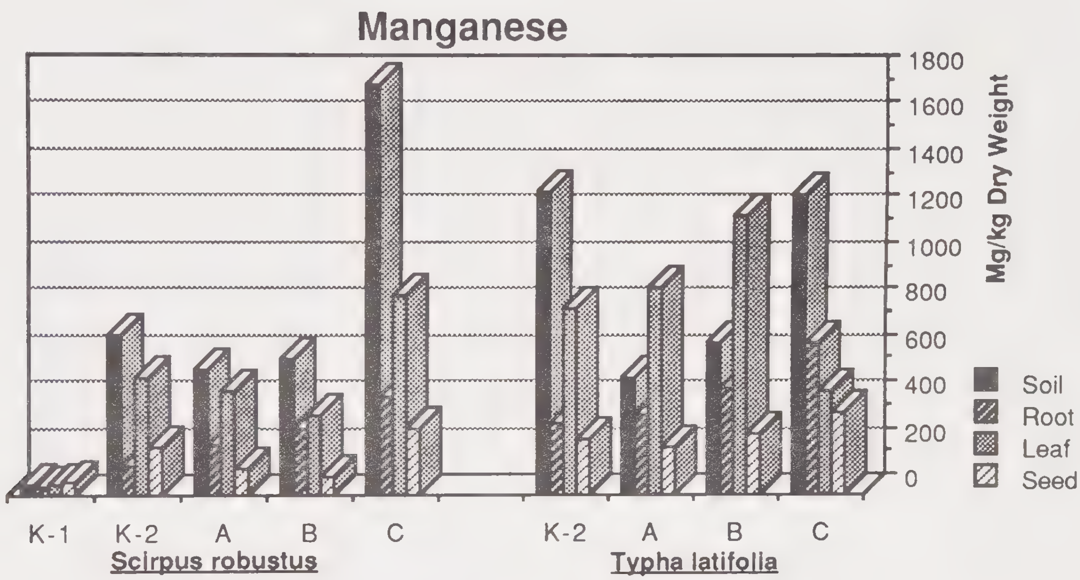


FIGURE 32. LEAD AND MANGANESE IN VEGETATION

of System B is characterized by a high frequency of young Scirpus, and to a lesser extent, Typha plants recently colonizing the area within the last two growing seasons. Although there are no data available on lead uptake in Scirpus and Typha plant parts, other metals -- such as manganese and zinc -- can be taken up in higher levels in new Typha shoot material as shown in Table 30.

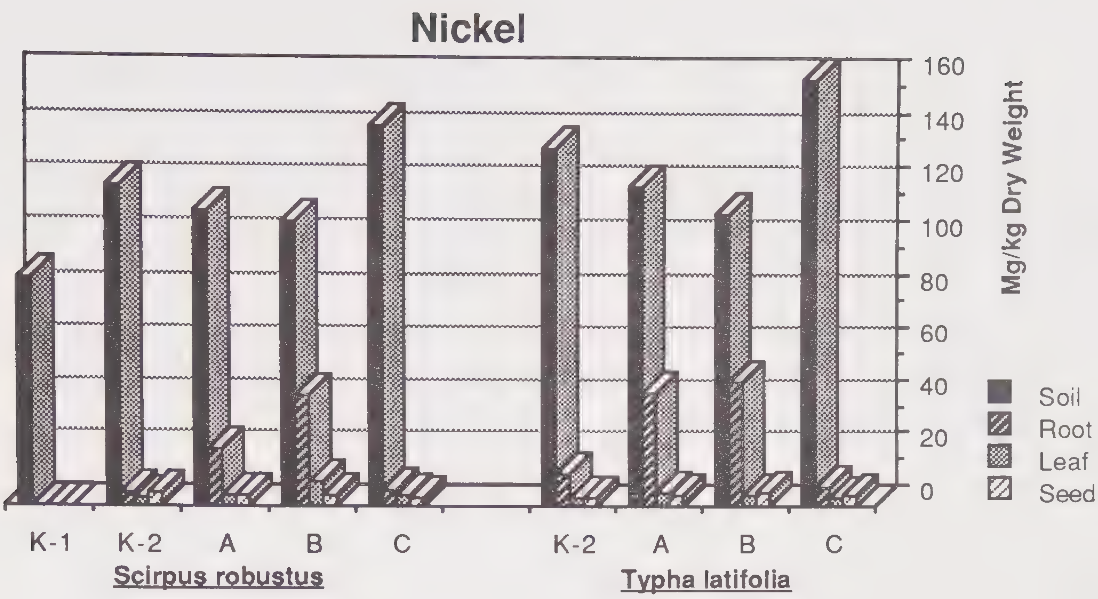
Scirpus root levels ranged from 2.7 to 15.8 mg-Pb/kg-dry plant; leaf values ranged from 2.4 to 11.4 mg-Pb/kg-dry plant; and fruit levels ranged from 3.4 to 8.3 mg-Pb/kg-dry plant. The highest uptake ratios (65-57%) occurred in root and leaf tissues in Systems A and B. Total plant uptake of lead ranged from 7.6 to 10.1 mg/m^2. Data from other studies are limited. Leaf levels of 13 mg-Pb/kg-dry plant were reported by Mudroch and Capobianco (1979). The Scirpus samples from DUST Marsh are below that level.

Typha root levels ranged from 6.2 to 13 mg-Pb/kg-dry plant; leaf values ranged from 4 to 17 mg-Pb/kg-dry plant; and fruit levels ranged from 3.7 to 6.2 mg-Pb/kg-dry plant. The highest uptake ratios occurred in System A root (43%) and System B leaf (106%) tissues. No data for comparison of seed and root concentrations are available and only one study reported leaf concentrations. Typha leaf levels are higher than those found by Mudroch and Capobianco (1979) of 2.6 to 5.5 mg-Pb/kg-dry plant. Total plant uptake for Typha ranged from 19.2 to 28.1 mg/m^2 -- up to 4 times greater than Scirpus due to greater biomass and uptake rates.

Manganese

Manganese levels among the plant parts by species and system are shown in Figure 32. Scirpus root levels ranged from 35.7 to 423 mg-Mn/kg-dry plant; leaf values ranged from 43.3 to 860 mg-Mn/kg-dry plant; and fruit levels ranged from 54 to 283 mg-Mn/kg-dry plant. The highest uptake ratios (72-83%) occurred in Systems K-2 and A leaf tissues. Manganese is an important micronutrient in Scirpus plant growth and is readily concentrated in leaf tissues. Data for manganese concentrations from other studies are not available. Total plant uptake for manganese from Table 35 ranged from 932 to 1681 mg/m^2.

Typha root levels ranged from 313 to 657 mg-Mn/kg-dry plant; leaf values ranged from 447 to 1200 mg-Mn/kg-dry plant; and fruit levels ranged from 207 to 350 mg-Mn/kg-dry plant. From the analysis of variance data in Table 33, plant species and plant part together accounted for a statistically significant source of manganese variation. Typha leaf tissue took up 34 to 185 percent of the background soil concentration. Low soil pH -- between 4.5 and 5.5 at System A during November 1984 -- probably contributed to high manganese uptake. Low pH increases the solubility of metal ions such as zinc, manganese and nickel and cause excessive uptake in plant tissues. Manganese is an important micronutrient in Typha plant growth and readily concentrated in leaf and fruit tissues. The cattail



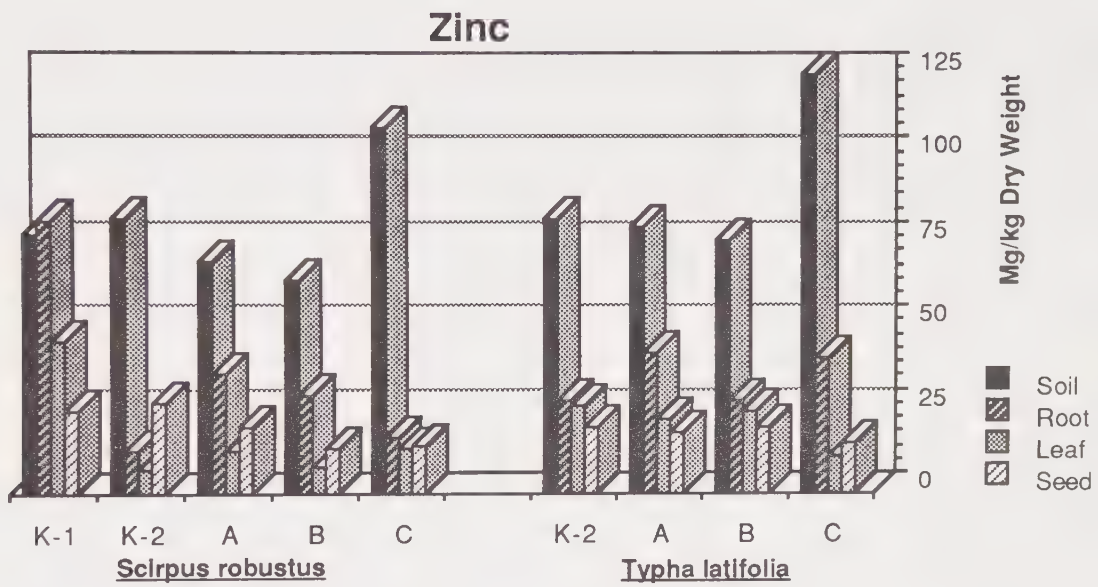


FIGURE 33. NICKEL AND ZINC IN VEGETATION

stands from which the samples were taken appeared to be healthy and vigorous. Total plant uptake of lead (from Table 35) ranged from 1432 to 2226 mg/m^2 -- about twice as much as Scirpus. The manganese levels found in the DUST Marsh samples fall within the ranges reported by Taylor and Crowder (1983) at 28 sites within the vicinity of a copper smelter. Manganese was consistently high at a majority of the sites, which probably indicates a typical plant uptake pattern.

Nickel

The mean nickel concentrations of root, leaf and seed plant parts are compared by plant species and station in Figure 33. From Table 33, plant part -- specifically roots and tubers -- accounted for the major source of variation. Root nickel concentrations in Scirpus ranged from not detectable to 41.8 mg-Ni/kg-dry plant. Leaf levels ranged from not detectable to 8.7 mg-Ni/kg-dry plant -- below the <6 to 144 mg-Ni/kg-dry plant levels reported from various studies on natural wetland systems in Table 31. Seed concentrations ranged from not detectable to 5.1 mg-Ni/kg-dry plant. There were no reported seed and root values in the literature for comparison. Total Scirpus uptake of nickel ranged from 12.1 to 15.9 mg/m^2 (Table 35).

Typha root levels ranged from 6.2 to 13 mg-Ni/kg-dry plant; leaf values ranged from 4 to 17 mg-Ni/kg-dry plant; and fruit levels ranged from 3.7 to 6.2 mg-Ni/kg-dry plant. The highest uptake ratios occurred in System A root (36%) and System B leaf (43%) tissues. Total Typha uptake ranged from 17.2 to 27.4 mg/m^2 -- about twice as much as Scirpus. The nickel levels found in the DUST Marsh samples fall within the ranges reported by Taylor and Crowder (1983) and Kaufman and Jones (1980).

Zinc

The relative concentrations of zinc occurring in the various plant parts by species and locations are shown in Figure 33. From the analysis of variance on Table 33, plant part represents the most significant source of variation. Scirpus root levels ranged from 12.5 to 81.3 mg-Zn/kg-dry plant; and fruit levels ranged from 13.8 to 27.3 mg-Zn/kg-dry plant. The highest uptake ratios occurred in root tissues from System K-1 (106%), System A (52%) and System B (46%). Zinc is an important micronutrient, second in importance to manganese. The zinc levels found in the DUST Marsh samples fall within the ranges reported by the various studies in Table 31. Total plant uptake rates from Table 35 range from 30 to 46 mg/m^2.

Typha root levels ranged from 17 to 81.3 mg-Zn/kg-dry plant; leaf values ranged from 6.9 to 45.7 mg-Zn/kg-dry plant; and fruit levels ranged from 13.8 to 27.3 mg-Zn/kg-dry plant. The highest uptake ratios occurred in System A root (52%). As discussed earlier, the low soil pH under Typha in System A could induce increased zinc solubility and lead to increased zinc uptake in plant tissues. Due to greater biomass and uptake rates, total Typha uptake ranged from 66 to 141 mg/m^2 -- over 4.5 times greater

than Scirpus. The zinc levels found in the DUST Marsh samples were not excessively high and fell within the ranges reported by Taylor and Crowder (1983) and Kaufman and Jones (1980).

The literature indicates that Typha is able to occupy a variety of industrially-degraded habitats, such as acid-mine drainage in Western Pennsylvania (Buchauer, 1973) and de-vegetated areas near smelters in Sudbury, Ontario (Taylor and Crowder, 1983). In a study of Typha latifolia genotypes from sites near a zinc smelter and from control sites, McNaughton et al (1974) found growth inhibition on heavily polluted soils, but no statistically-significant genotypic differences in growth rates. McNaughton concluded that some peculiarity of the physiology of Typha, in comparison with other plants, conferred a general resistance to heavy metals -- possibly due to a cell wall metal precipitation mechanism.

Long-Term Bioaccumulation

Evaluation of plant metals concentrations (Figures 31, 32 and 33) occurring at Station K-1 and System B against the remaining sampling stations gives an indication of short-term uptake versus long-term accumulation. Station K-1 (on the K-Line channel in front of the Newark Blvd. Flood Gates) had been cleared of vegetation and excess sediment during Summer 1984. Subsequently, during Winter 1984-85, approximately 2-3 ft of fine sediment had been deposited at the site from runoff flows. By Spring 1985, Station K-1 supported a thick stand of alkali bulrush, which had primarily sprouted from seed. Plant samples collected from this site had very small root tubers and represented one season's growth. As described previously, System B is a newly-constructed marsh system with scattered stands of alkali bulrush colonizing the overland flow area. Plant samples collected from this site generally represented 1-2 years of growth. By comparison, Station K-2 (K-Line channel upstream of Debris Basin), System A south perimeter and System C were all thickly covered with mature vegetation, and plant/root samples from these sites represented growth spanning 1-5 years or more.

For Scirpus, Stations K-1 and System B yielded the highest accumulations of chromium (50 mg/kg), copper (18-19 mg/kg), lead (8-16 mg/kg) and zinc (26-85 mg/kg) all primarily in the root tissues. System B yielded the highest nickel concentration (40 mg/kg) and System A exhibited comparable but slightly lower levels of copper, lead and zinc. The largest concentration of manganese in Scirpus occurred only in System C leaf tissue (850 mg/kg). These data indicate that new growth, as represented in Station K-1 and System B, tends to accumulate chromium, copper, lead, nickel and zinc rapidly. Metals concentrations in mixed-age or mature stands are generally lower indicating either lower uptake rates and/or re-release of metals from aging plant material. High manganese levels in System C suggest that manganese uptake is constant and that mature Scirpus

stands exhibit long-term bioaccumulation. At all sampling sites, with the exception of System B, Scirpus growth was tall and vigorous. System B growth was small and thin, which was probably attributable to poor soil conditions on the developing marsh site.

For Typha, Systems A and B yielded the highest accumulations of chromium (seeds = 60-65 mg/kg), copper (root = 18-20 mg/kg), lead (leaf = 17 mg/kg) and nickel (root = 42-48 mg/kg). Systems A and C exhibited slightly elevated zinc levels (root = 40-42 mg/kg); whereas Station K-2, and Systems A and B all showed high manganese levels (leaf = 800-1200 mg/kg). Systems A and B, in particular, exhibited leaf concentrations above ambient soil levels. Comparative data were not available for Station K-1 because cattails were not found at this site. The data generally indicate that Typha follows a similar pattern to Scirpus: new growth tends to accumulate chromium, copper, lead and nickel at the highest rates. Manganese uptake is high through all age stands, although a drop in manganese levels in System C (leaf = 450 mg/kg) may indicate re-release of manganese in aging Typha stands. At all sampling sites, Typha growth was tall and vigorous. System B growth was small, as was the Scirpus growth, but relatively vigorous. The small growth is probably attributable to poor soil conditions, however, it is important to note that Typha accounted for only a minor portion (3%) of System B vegetation.

SECTION 9
HEAVY METALS ANALYSES IN FISH

Heavy metals generally occur at very low concentrations in water and may increase in sediment and plant tissues through various interactions and uptake mechanisms. Animal species on secondary and tertiary trophic levels have the potential to bioaccumulate heavy metals beyond the surrounding environmental levels. A total of 12 fish seines (4 sample dates x 3 stations per date) and 18 trap nights (2 sample dates x 3 stations per date x 3 depths per station) were conducted. To provide a comparison to a natural wetland system, 3 trap nights (1 station x 3 depths) were also conducted in the Coyote Hills Park South Marsh (SM) during November 1985. The South Marsh is 1/2 mile southeast of the DUST Marsh and receives predominantly non-urban runoff. A summary of the catch efforts by sample date and system is presented in Table 36. A presentation of the fish species composition by percentages is shown in Figure 34.

TABLE 36. FISH SAMPLING SUMMARY, 1984-85 FISH SEINING

Date	System	Blackfish	Carp	Gambusia	Stickleback	Sculpin
10/24/84	A	15	17	11	8	2
4/02/85	A	4	0	0	0	0
6/05/85	A	15	18	0	45	2
7/11/85*	A	0	0	0	1	3
7/23/85*	A	0	0	0	0	3
7/23/85*	B	0	0	0	0	7
7/23/85*	C	0	0	16	38	3
10/10/85	A	2	19	24	57	0
11/27/85*	SM	0	0	18	11	21

* collected in funnel traps

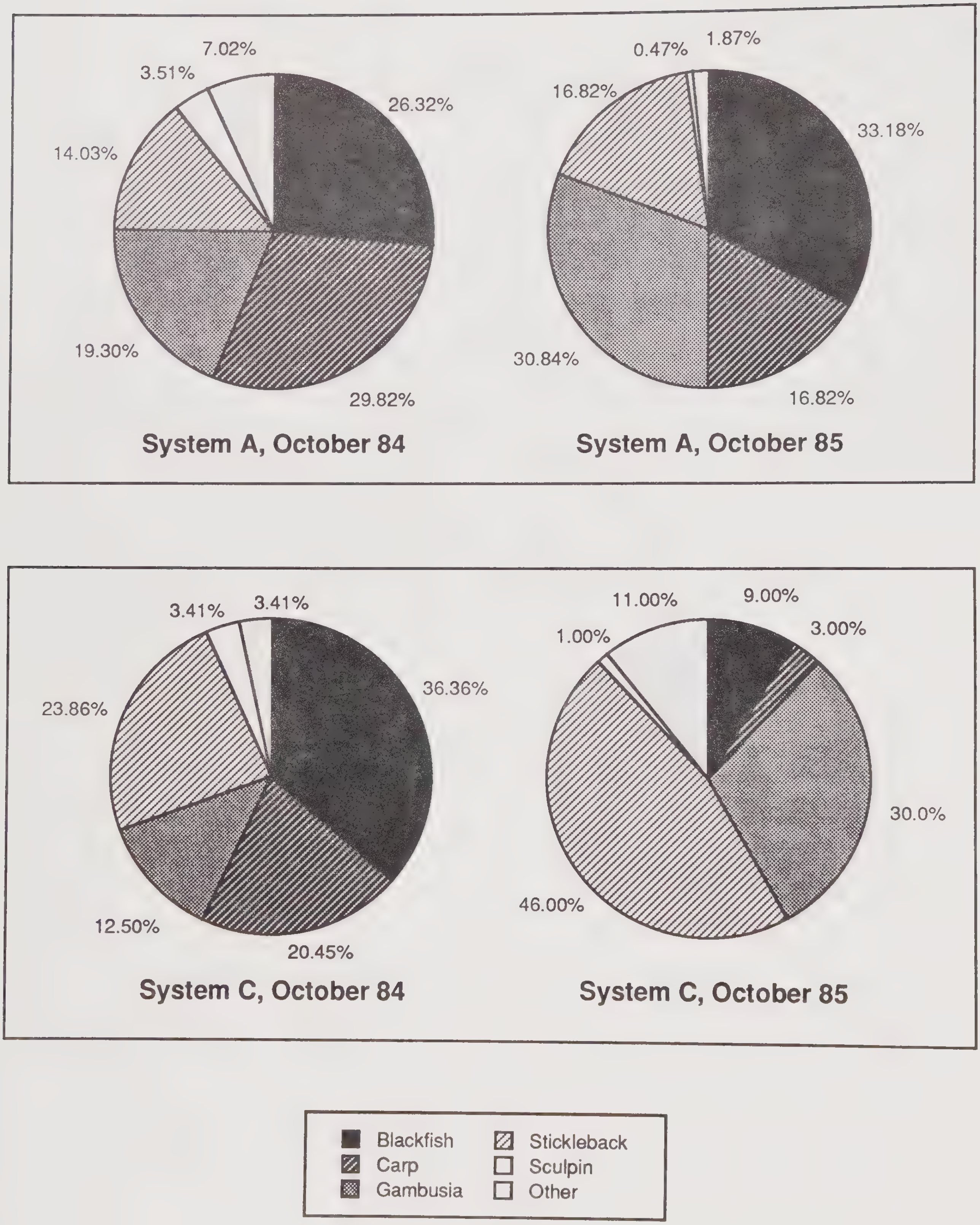


FIGURE 34. FISH SPECIES COMPOSITION

Heavy metal analyses for blackfish and carp specimens were performed on the liver tissues only at the suggestion of the California Department of Fish and Game Laboratory (N. Morgan, personal communication). The Fish and Game personnel reported negligible levels of heavy metals had been found in these species from previous analyses and testing of liver tissues might yield detectable metal levels. The other study species (stickleback, gambusia and sculpin) were analyzed as composite whole fish samples since they were too small (< 60 mm) for liver dissection. A graphic presentation of heavy metals concentrations by species, date and system is shown in Figures 35 through 39. The laboratory analysis data is presented in Appendix C. A summary of the fish analyses from 1984 and 1985 is given in Table 37. A two-factor analysis of variance comparing the significance of species and location (systems A, B and C) is presented in Table 38. On the cadmium analysis of variance, blackfish and carp were not included because either sufficient sample volumes were not available or the concentrations were below the analysis detection limit. Table 39 shows the data from a supplemental analysis done in 1986. This sampling was done to verify heavy metal concentrations observed in the earlier analysis. No analysis of variance was performed on sampling dates since not all species were caught during each sample effort.

An extensive literature search was conducted for data on heavy metals in the fish species under study. The search had limited results as presented in Table 40. The table includes notations for fish samples that exceeded the Elevated Data Level (EDL) guideline developed by the California Department of Fish and Game in the 1984 Toxic Substances Monitoring (TSM) Program Report. The EDL is based on a cumulative summary of all findings from a given chemical and tissue type (flesh, liver or whole body) recorded by the Toxic Substances Monitoring Program which began in 1976. All data for a given tissue type and chemical were placed in rank order and percentile rankings were calculated. An 85% EDL of 25 ppm denotes that 85 percent of the findings were below 25 ppm and 15 percent of the findings were equal to or greater than 25 ppm. The EDLs were calculated as a composite of all species (except for salmonids), and therefore should only be used as guidelines. Fish values appearing above the 85% and 95% EDL alert the researcher to possible pollution problems. However, the results should be viewed in light of other fish or fish species from that area in the same sample year and previous years. The Fish and Game EDLs are based on a large number of liver samples. However flesh samples and whole body samples were less common in the TSM study and we do not believe that a useful EDL can be developed from TSM data for these tissues.

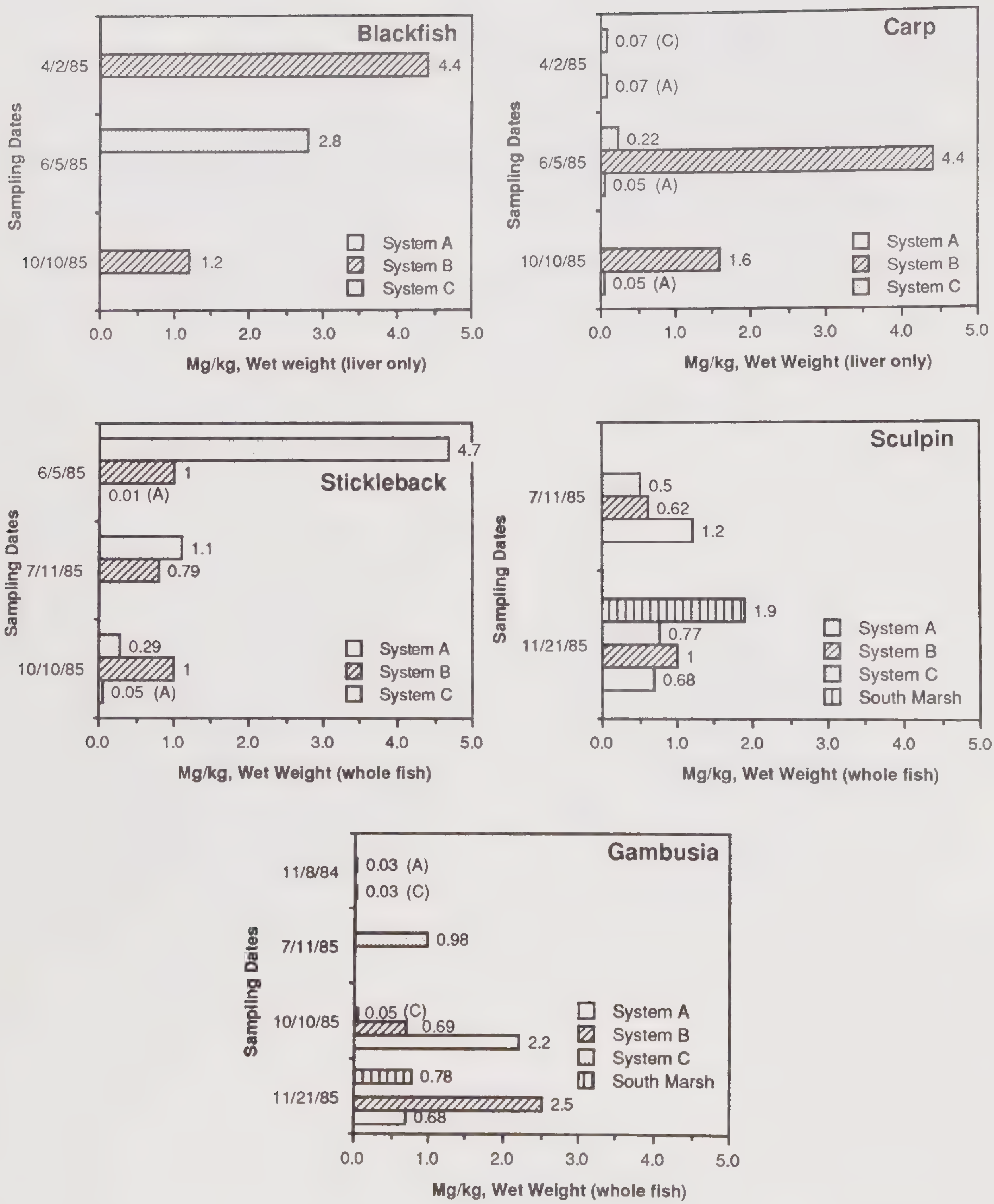


FIGURE 35. CHROMIUM CONCENTRATIONS IN FISH TISSUE

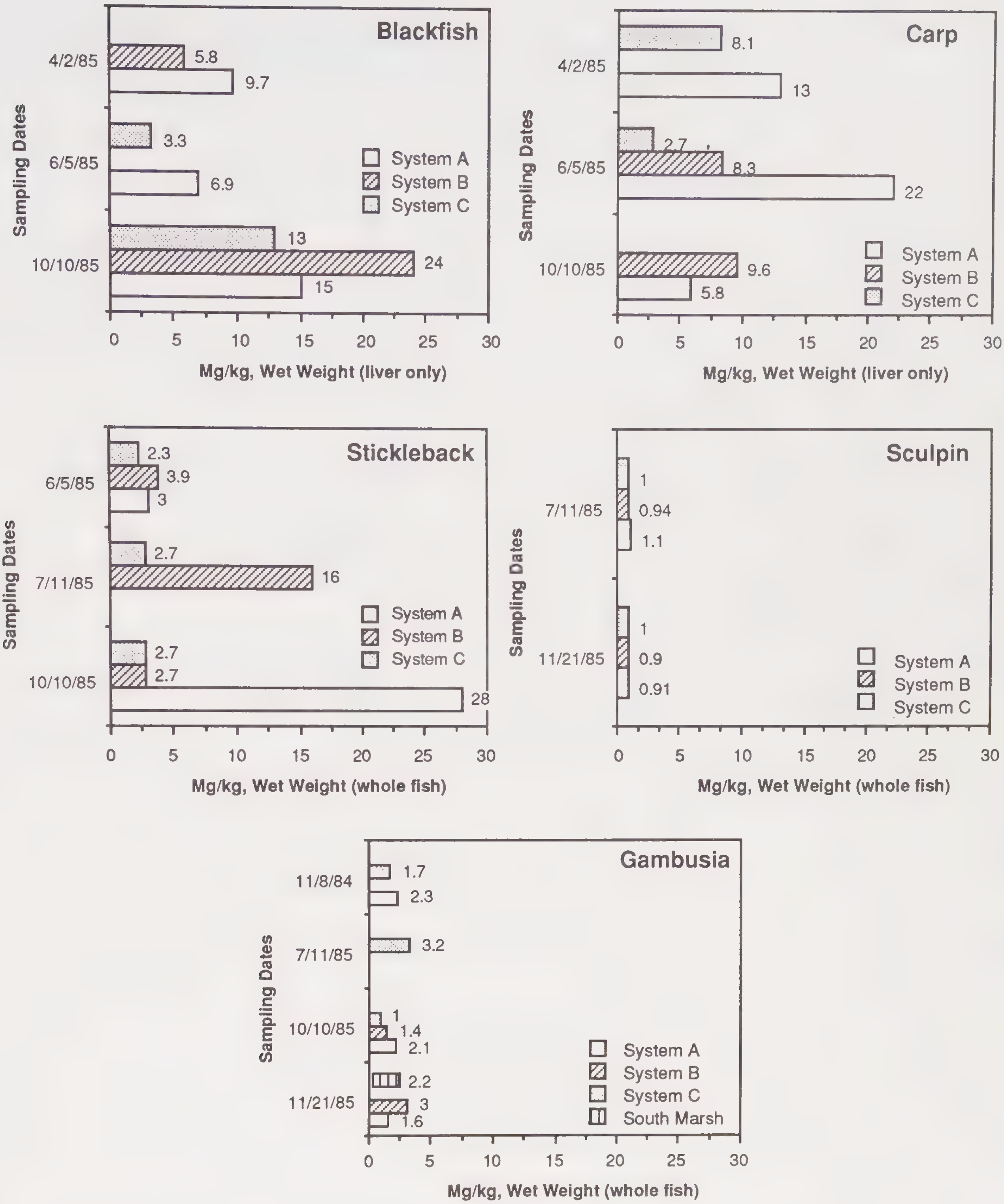


FIGURE 36. COPPER CONCENTRATIONS IN FISH TISSUE

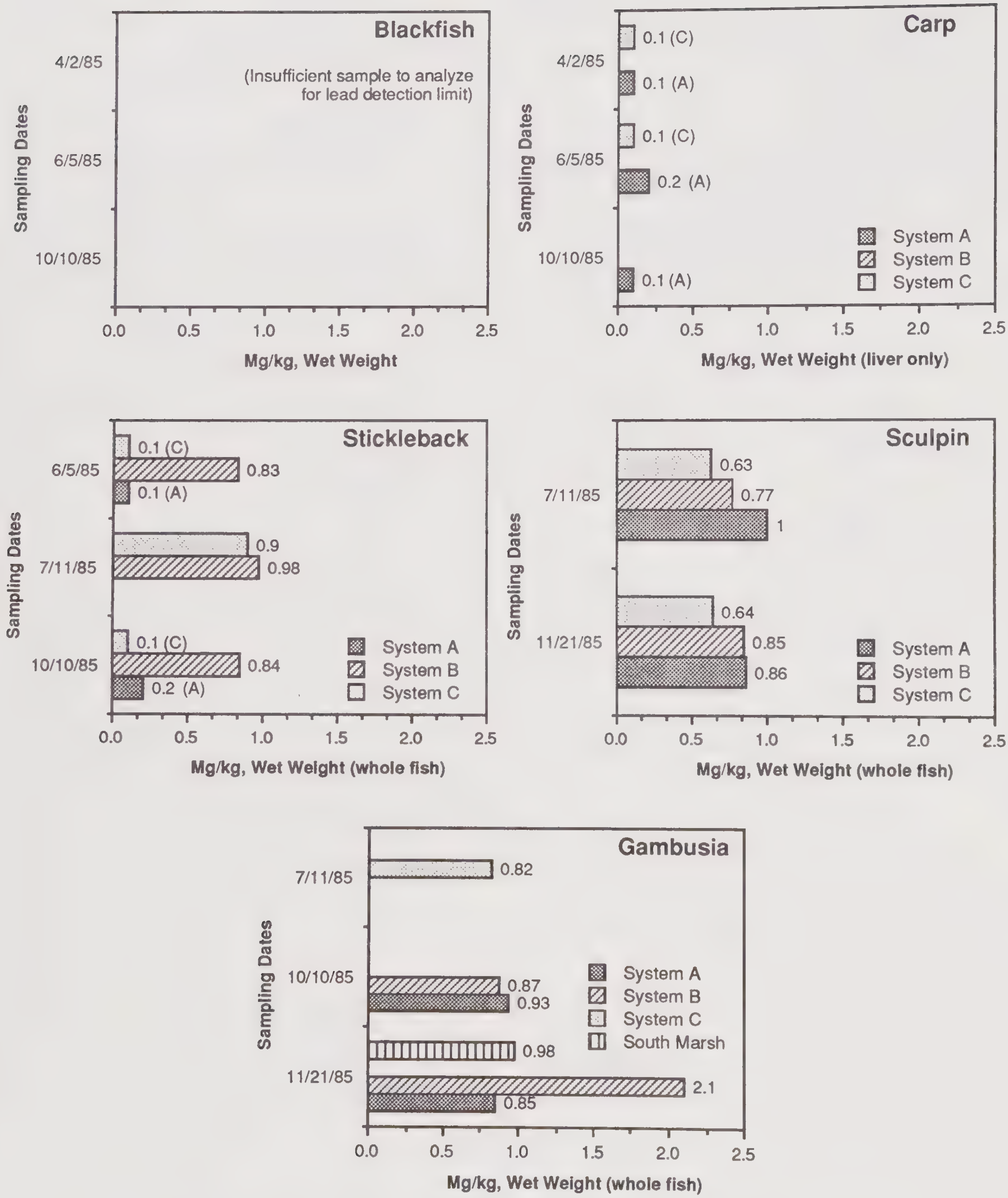


FIGURE 37. LEAD CONCENTRATIONS IN FISH TISSUE

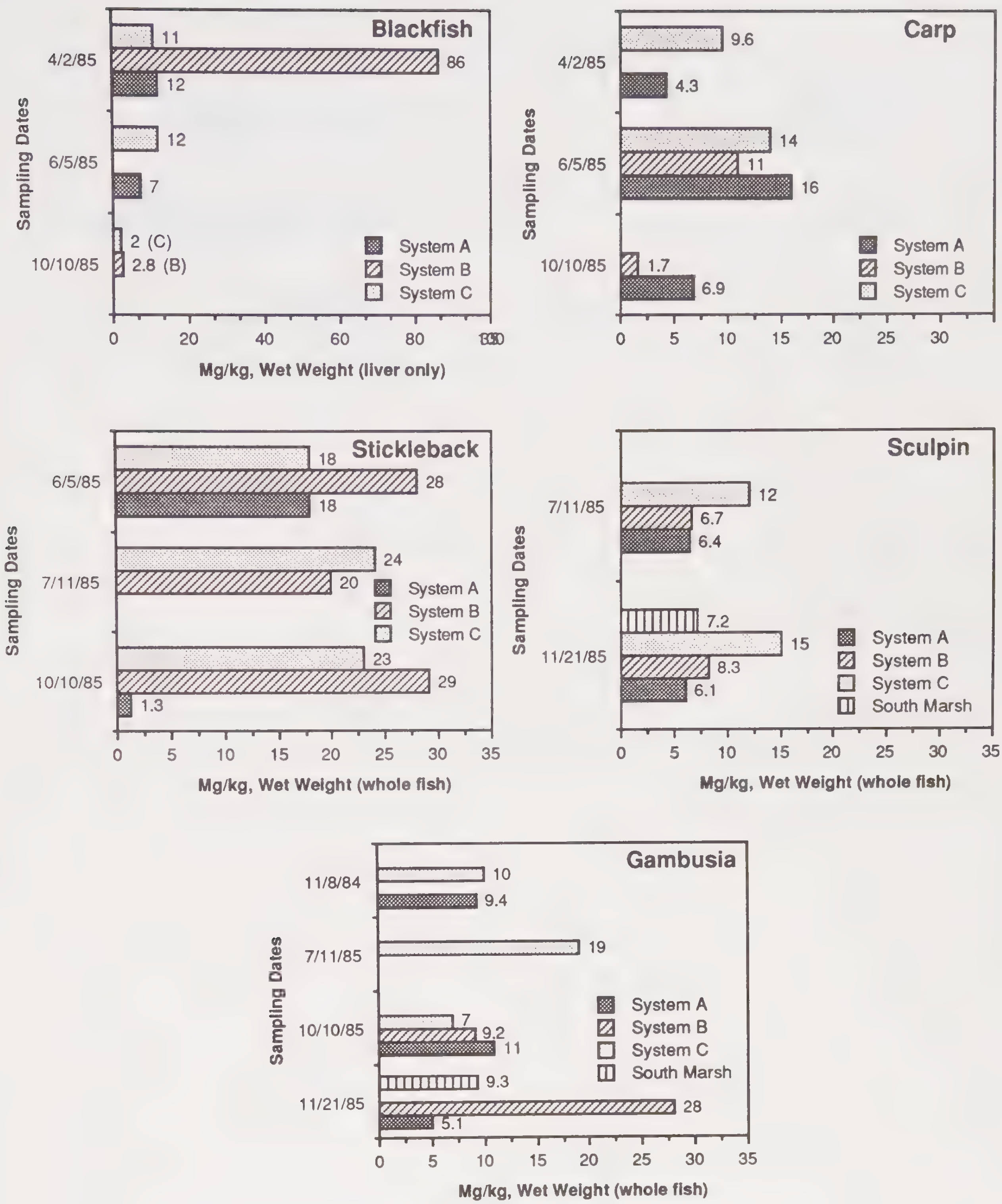


FIGURE 38. MANGANESE CONCENTRATIONS IN FISH TISSUE

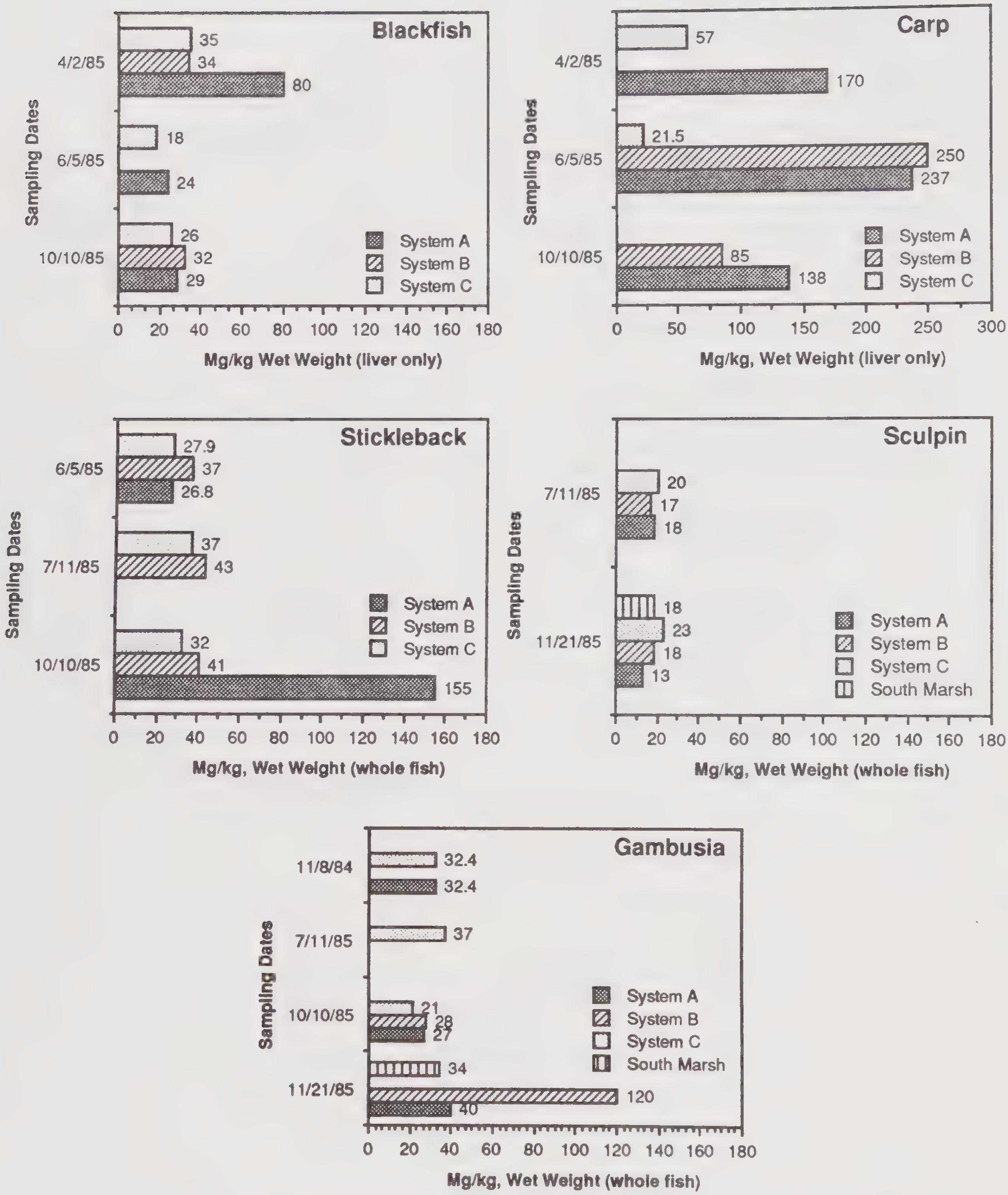


FIGURE 39. ZINC CONCENTRATIONS IN FISH TISSUE

TABLE 37. FISH ANALYSES SUMMARY
Mean Concentration (PPM-Wet Weight)[a]

System	Species	Chromium	Copper	Lead	Manganese	Zinc
A	Blackfish	a	11.0*	a	9.5	44.3*
	Carp	.057*	14.0*	.13	9.1	182*
	Stickleback	.075	16.0	.15	9.7	30.9
	Gambusia	.97	2.0	.89	8.5	33.1
	Sculpin	.94	1.0	.93	6.3	15.5
B	Blackfish	2.8*	15.0*	a	44.0	33.0*
	Carp	3.0*	9.0*	.88*	6.4	168*
	Stickleback	.93	7.5	1.5	26.0	40.3
	Gambusia	1.6	2.2	.81	19.0	74.0
	Sculpin	.81	0.92	1.0	7.5	17.5
C	Blackfish	2.8*	8.2*	.10	8.3	26.3
	Carp	.15*	5.4	.37*	12.0	39.3*
	Stickleback	.62	2.6	.82	22.0	32.3
	Gambusia	.35	2.0	.64	12.0	30.1
	Sculpin	.64	1.0	.42	14.0	21.5
SM	Gambusia	.78	2.2	.98	9.3	34.0
	Sculpin	1.9	2.4	2.4	7.2	18.0

a Insufficient sample volume for analyses of lead, chromium and nickel
Note: Whole fish analyses except for liver analyses on blackfish and carp.

* Exceeds 85% EDL guidelines for fish liver only: Cr $\geq$ 0.03 ppm; Cu $\geq$ 6.91 ppm; Pb $\geq$ 0.2 ppm; Zn $\geq$ 30 ppm, (No EDL for whole fish)

SM = South Marsh control area at Coyote Hills Park.

TABLE 38. TWO-FACTOR ANALYSIS OF VARIANCE ON FISH DATA

Metal[a]	F-test for Main Effects: Joint Effects	Species	System
Chromium[b]	1.23	0.37	2.74
Copper[b]	0.65	3.65*	1.75
Lead[c]	0.61	3.76*	2.41
Manganese[b]	1.00	1.03	2.01
Zinc[b]	1.88	7.95**	4.30*

* significant at Probability <.05 ** significant at Probability <.01

a Insufficent data for analyses of cadmium and nickel

b Degrees of freedom: Joint effects (4,13); Species (4,13); System (2,13)

c Degrees of freedom: Joint effects (4,13); Species (3,13); System (2,13)

Table 39. FISH ANALYSES, 15 October 1986
COYOTE HILLS MARSH (ppm, wet weight)

Parameter		n	$\bar{x}$	s	Cd	Cr	Cu	Pb	Zn	Se
Sediment					0.67	67	16	9.4	35	<0.5
Blackfish										
Length, mm		13	189.23	14.10						
Weight, kg		13	.975							
Liver					0.25*	2.0**	25.*	3.5*	28	<0.5
Flesh					0.25	<1.0	4.0	3.5***	5	<0.5
Carp										
Length,mm		6	305.	19.28						
Weight, kg		6	5.49	0.86						
Liver					0.75*	1.0**	22.0*	9.0*	200.**	0.60
Flesh					0.62***	<1.0	3.0	7.0***	7.5	<0.5
Gambusia										
Length,mm		25	33.6	14.77						
Weight, gm		25	0.95							
Whole Fish	DUST Marsh				0.25	1.0	22	<1.2	34	<0.5
	South Marsh A				<0.25	<1.0	<1.2	<1.2	22	<0.5
	South Marsh B				<0.25	<1.0	1.2	<1.2	24	<0.5
Stickleback										
Length,mm		32	45							
Weight, gm		32	0.81							
Whole Fish					0.25	1.0	6.5	2.5	38	<0.5
Median International Standard (fish flesh)					.30	1.0	20	2.0	45	2.0
TSM Elevated Data Level (EDL)										
85^{th} percentile (liver)					0.43	0.03	6.91	0.2	30	3.5
95^{th} percentile (liver)					2.1	0.10	28.9	0.2	38	5.8

* Exceeds TSM EDL 85^{th} percentile (liver)
** Exceeds TSM EDL 95^{th} percentile (liver)
*** Exceeds Median International Standard

Note: Fish samples were collected in System B unless otherwise noted.

TABLE 40. REPORTED METALS CONCENTRATIONS IN CALIFORNIA FISH
(PPM Wet Weight)

Species/Location	Cd	Cr	Cu	Ni	Pb	Zn	Se
Sculpin-Liver							
Klamath River, 1978	0.50*	<0.10	2.2	<0.1	0.36**	38*	-
Klamath River, 1979	0.31	<0.02	2.8	<0.1	0.4 **	32*	-
Klamath River, 1980	0.15	<0.02	2.8	<0.1	0.2 *	25	-
Klamath River, 1981	0.09	<0.02	1.6	0.1	0.2 *	19	-
Klamath River, 1983	0.17	<0.02	1.8	<0.1	0.2 *	17	-
Klamath River, 1984	0.13	<0.04	1.2	<0.1	0.1	26	0.9
Trinity River, 1978	0.28	<0.10	4.5	<0.1	0.7	27	-
Putah Creek, 1978	0.54*	<0.10	5.1	-	<0.7	38*	-
Eel River-Scotia, 1978	0.24	<0.10	1.8	<0.1	<0.7	49**	-
Eel River-Scotia, 1979	0.14	<0.02	3.1	<0.1	0.1	29	-
Eel River-Scotia, 1980	0.23	<0.02	2.6	<0.1	0.1	26	-
Eel River-Scotia, 1984	0.15	<0.04	2.8	<0.1	<0.1	30	1.1
San Lorenzo R., 1978	0.98*	<0.10	4.9	-	0.62**	38*	-
San Lorenzo R., 1979	1.19*	<0.02	6.4	<0.1	0.1	43**	-
San Lorenzo R., 1980	1.10*	<0.02	4.6	0.2	<0.1	39**	-
Smith River, 1980	0.10	0.03	1.8	0.1	0.3*	17	-
Smith River, 1983	0.12	0.06*	2.6	<0.1	0.4**	15	-
Smith River, 1984	0.17	0.07*	2.2	<0.1	0.90**	31	1.4
McCloud R., 1980	0.15	<0.02	7.3*	0.6**	<0.1	32*	-
Mad River, 1981	0.06	<0.02	1.4	<0.1	<0.1	17	-
Mad River, 1982	0.08	<0.02	2.4	0.1	<0.1	19	-
Carson R., 1983	0.05	<0.02	3.4	0.1	<0.1	21	-
Truckee R., 1983	0.04	<0.02	3.1	<0.1	<0.1	21	-
Carp - Flesh							
Harbor Pk. Lake, 1984	<0.01	<0.04	0.40	<0.1	<0.1	14	0.4
Goldfish - Flesh							
Harbor Pk. Lake, 1983	<0.01	<0.02	0.68	<0.1	<0.1	32	-
Harbor Pk. Lake, 1983	<0.01	<0.02	0.70	<0.1	<0.1	36	-
Harbor Pk. Lake, 1984	<0.01	<0.04	0.57	<0.1	<0.1	25	0.5
Legg Lake, 1984	<0.01	<0.04	0.30	0.1	<0.1	15	<0.2
Gambusia - Whole Fish							
Kesterson Res.-5, 1984	<0.01	0.11	3.7	<0.1	<0.1	35	27**
Kesterson Res.-6, 1984	<0.01	<0.04	3.3	0.2	<0.1	30	34**
Elevated Data Level (EDL) - Liver							
85th percentile	0.43	0.03	6.91	0.2	0.1	30	3.5
95th percentile	2.1	0.1	28.9	0.2	0.3	38	5.8

Source: California State Water Resources Control Board, 1985
* Exceeds EDL 85th percentile
** Exceeds EDL 95th percentile

The main limitations of Table 40 are:

1. The sculpin specimens were analyzed for liver tissue only. The average sculpin size was 95-101 mm; whereas the DUST Marsh specimens were analyzed as whole fish of 60-70 mm size.

2. Carp and its close relative the goldfish were analyzed for flesh tissue only and fish size was variable. DUST Marsh carp were analyzed for liver tissue. Only one set of samples from October 1986 was analyzed for flesh only.

3. The gambusia specimens were collected from Kesterson Reservoir, CA -- an area with a serious selenium pollution problem. The input of agricultural drain waters may have also cause atypical metal loadings.

ANALYSIS OF FISH DATA

Cadmium

During the 1984-85 surveys, insufficient samples were collected to analyze for cadmium. In the 1986 survey, extra seines were conducted to catch more fish. Cadmium was low in all species except carp, which exceeded the 85th percentile liver EDL and the Median International Standard for fish flesh. In blackfish and carp, liver and flesh concentrations were roughly the same. None of the species accumulated cadmium beyond sediment levels.

Chromium

Mean chromium concentrations in blackfish and carp liver samples ranged from 0.057 to 3.0 mg-Cr/kg-wet liver weight. Mean whole body concentrations ranged from 0.075 to 1.0 mg-Cr/kg-wet fish weight in stickleback, 0.35 to 1.6 mg-Cr/kg-wet fish weight in gambusia, and 0.64 to 1.9 mg-Cr/kg-wet fish weight in sculpin. The sediment level was 67 mg-Cr/kg wet weight. From the analysis of variance in Table 38, variance between species and between the A, B and C systems was not statistically significant. One observation from the data is that blackfish and carp livers, as well as flesh tissue, do not significantly accumulate chromium above stickleback or gambusia levels.

In comparison to other reported studies, whole fish chromium levels in DUST Marsh gambusia were as much as an order of magnitude higher than that found in Kesterson Reservoir gambusia (<0.04 to 0.07 mg-Cr/kg-wet fish weight). However, comparison of DUST Marsh gambusia and sculpin against those found in the control South Marsh (0.78 to 1.9 mg-Cr/kg-wet fish weight) show comparable levels in gambusia and lower levels in sculpin from the DUST Marsh. Blackfish and carp livers appeared to be above the 95% EDL in Systems A and B. Since the EDL does not include liver analyses from these species, the significance of the high chromium levels can not be evaluated without more comparisons from the same species.

Copper

Mean copper concentrations in blackfish and carp liver samples ranged from 5.4 to 25 mg-Cu/kg-wet liver weight. Mean whole body concentrations ranged from 2.6 to 16 mg-Cu/kg-wet fish weight in stickleback, 2.0 to 2.2 mg-Cu/kg-wet fish weight in gambusia; and 0.92 to 1.0 mg-Cu/kg-wet fish weight in sculpin. From Table 38, variance between the species was statistically significant indicating that blackfish and carp liver samples showed relatively higher copper accumulations. However, the blackfish and carp correlations probably are not conclusive since these specimens were generally older than the smaller fish species and may have been accumulating metals over a longer period of time. Carp and blackfish livers accumulated copper 6 to 7 times more than flesh tissues. The liver tissues of these fish, as well as gambusia - whole body, appear to be able to accumulate copper up to the ambient sediment level.

In comparison to other reported studies, whole fish copper levels in DUST Marsh gambusia were lower than the levels found in Kesterson Reservoir gambusia (3.3 to 3.7 mg-Cu/kg-wet fish weight) or sculpin livers (1.2 to 2.8 mg-Cu/kg-wet fish weight). Similarly, comparisons of DUST Marsh gambusia and sculpin against those found in the control South Marsh (2.2 to 2.4 mg-Cu/kg-wet fish weight) show comparable levels. DUST Marsh blackfish and carp flesh levels (3.0 to 4.0 mg-Cu/kg-wet fish weight) are significantly higher than carp and goldfish flesh samples (0.30 to 0.57 mg-Cu/kg-wet fish weight) reported in Table 40; no data are available to compare liver-to-flesh ratios for these species. Blackfish and carp livers appeared above the 85% EDL in Systems A, B and C. Since the EDL does not include liver analyses from these species, the significance of the high copper levels cannot be evaluated without more comparisons from the same species.

Lead

Mean lead concentrations in blackfish and carp liver samples ranged from not detectable to 9.0 mg-Pb/kg-wet liver weight. Mean whole body concentrations ranged from 0.15 to 2.5 mg-Pb/kg-wet fish weight in stickleback, 0.64 to 0.89 mg-Pb/kg-wet fish weight in gambusia, and 0.42 to 1.0 mg-Pb/kg-wet fish weight in sculpin. From Table 38, variance between species was statistically significant indicating that stickleback and gambusia samples showed relatively higher lead accumulations. Blackfish and carp livers, as well as flesh tissues, can significantly accumulate lead above stickleback or gambusia levels as shown in Table 37. However, between black and carp liver and flesh, the levels are similar. As noted in Table 37, blackfish and carp flesh levels are above the Median International Standard for fish flesh. In comparison to other reported studies, whole fish lead levels in DUST Marsh gambusia were up to 10 times higher than those found in Kesterson Reservoir gambusia (<0.10 to 0.2 mg-Pb/kg-wet fish weight) or sculpin livers (<0.10 mg-Pb/kg-wet fish weight). However, comparison of DUST Marsh gambusia and sculpin against those found in the control South Marsh (0.98 to 2.4 mg-Pb/kg-wet fish weight) show DUST Marsh gambusia and sculpin were well below the South Marsh levels. DUST Marsh carp flesh concentrations were 70 times greater than carp and goldfish

flesh samples (<0.10 to 0.10 mg-Pb/kg-wet fish weight) reported in Table 40 Carp livers appeared above the 95% EDL in Systems B and C, as well as blackfish liver in System B. Because the EDL does not include liver analyses from these species, the significance of the high lead levels can not be validated without more comparisons from the same species. In the 1984 TSM Report, rainbow and brown trout were found to accumulate copper at much higher levels than other fish (rainbow trout liver 75% EDL = 103 ppm; 90% EDL = 192 ppm). The blackfish and carp levels are well below those concentrations.

Manganese

Mean manganese concentrations in blackfish and carp liver samples ranged from 6.4 to 44 mg-Mn/kg-wet liver weight. Mean whole body concentrations ranged from 9.7 to 26 mg-Mn/kg-wet fish weight in stickleback, 8.5 to 19 mg-Mn/kg-wet fish weight in gambusia, and 6.3 to 14 mg-Mn/kg-wet fish weight in sculpin. From the analysis of variance in Table 38, variance between species and between A, B and C systems was not statistically significant. As with chromium, a possible inference is that blackfish and carp livers (and presumably flesh tissue as well) do not significantly accumulate manganese above stickleback or gambusia levels.

No reported data are available to compare DUST Marsh manganese concentrations or develop EDL levels. In comparisons of DUST Marsh gambusia and sculpin against those found in the control South Marsh (.98 to 2.4 mg-Mn/kg-wet fish weight), the DUST Marsh fish were 2 to 5 times greater than South Marsh levels. As discussed in the Soil and Vegetation Sections, Systems A and C surface soils and selected plant parts exhibit high levels of manganese probably due to saline groundwater intrusion. These backgound parameters may directly or indirectly affect manganese concentrations in gambusia and sculpin, however the data are insufficient to draw conclusive correlations.

Nickel

Nickel concentrations in the fish samples were generally at or below the detection limit (0.1 Mg/kg wet fish weight) and statistical comparisons could not be made. Nickel bioaccumulation does not appear to be a problem in the marsh.

Zinc

Mean zinc concentrations in blackfish liver samples ranged from 26.3 to 44.3 mg-Zn/kg-wet liver weight. For carp livers, mean zinc concentrations ranged from 39.3 to 200 mg-Zn/kg-wet fish weight. Mean whole body concentrations ranged from 32.3 to 40.3 mg-Zn/kg-wet fish weight in stickleback, 30 to 74 mg-Zn/kg-wet fish weight in gambusia, and 15.5 to 17.5 mg-Zn/kg-wet fish weight in sculpin. From Table 38, variance between species and system location were statistically significant indicating that carp liver samples from Systems A and B, as well as gambusia from System B, showed relatively high zinc accumulations. However, the carp correlations are not conclusive because the sample was biased by one large specimen weighing 1.4 kg and much older than the smaller fish species. No

explanations are available for the high gambusia levels observed in System B. Blackfish liver accumulated zinc nearly 6 times more than flesh tissue. Carp liver was nearly 28 times more than flesh and about 5 times higher than the sediments.

In comparison to other reported studies, whole fish zinc levels in DUST Marsh gambusia were up to 2 times higher than those found in Kesterson Reservoir gambusia (30 to 35 mg-Zn/kg-wet fish weight). Similarly, comparisons of DUST Marsh fish against those found in the control South Marsh show comparable levels in sculpin (18 mg-Zn/kg-wet fish weight) and lower levels in South Marsh gambusia (22-34 mg-Zn/kg-wet fish weight). DUST Marsh blackfish and carp flesh (5 to 7.5 mg-Zn/kg-wet fish weight) levels are about one-third of the carp and goldfish samples (14 to 25 mg-Zn/kg-wet fish weight) reported in Table 40. Blackfish and carp livers appeared above the 95% EDL in all systems. Since the EDL does not include liver analyses from these species, the significance of the high copper levels can not be validated without more comparisons from the same species.

Selenium

Selenium analyses were conducted only on the fish caught during the October 1986. With the exception of carp liver (0.60 mg-Se/kg-wet fish weight), all samples were below the detection limit (0.5 mg/kg wet fish weight). Therefore selenium accumulation does not appear to be a problem in the marsh.

Long-Term Bioaccumulation

Heavy metal accumulation in blackfish liver was significant for chromium, copper and lead. Both the 85% and 95% EDLs from the TSM study were exceeded. Carp liver accumulations were significant for cadmium, chromium, copper, lead and zinc. In addition, lead in blackfish flesh and cadmium and lead in carp flesh exceeded the Median International Standard. Human consumption of these fish would not be advisable. Analysis specimens of the two species were typically within the 3-5 year old age classes with some carp specimens perhaps as old as 7-10 years. This shows a significant potential for long-term bioaccumulation of heavy metals. However, the source of these metals is less clear. As discussed in the Soil Section, water quality has probably been affected by soil leachates from the newly-constructed marsh system. Thus, high background soil and sediment concentrations may be more significant than stormwater contributions. Additionally, the blackfish and carp may have migrated from the Coyote Hills Main Marsh and been subject to varying sediment and water conditions. With these factors in mind, the ability of carp and blackfish to accumulate heavy metals is proven, but the correlation of heavy metals concentration to stormwater runoff effects is inconclusive.

Long-term bioaccumulation in stickleback and gambusia is also not well understood. The life cycles of these fish are shorter and the typical specimens were about 1-3 years old. Compared to the literature reports, DUST Marsh gambusia showed higher levels of cadmium, chromium and nickel. However, the same soil conditions, as discussed previously for blackfish and carp, prevail.

SECTION 10
CONCLUSIONS

HYRDROLOGY AND WATER QUALITY

Dust Marsh Hydrology

Based on the discussion of runoff characteristics, storage volume, travel time and system interactions with the P-Line, the following conclusions can be made about marsh hydrology during the Winter 1984-85 and Winter 1985-86 seasons:

1. During moderate-to-large storms (0.8-1.5 in. rainfall depth) the areas inundated by stormwater increased by slightly over 4 acres or as much as 20 percent.

2. The average storage volume between storms was approximately 2.5×10^6 ft^3 or about 60 percent of the total storage volume of the marsh.

3. The leading edge of stormwater inflow into the marsh occurs approximately 5-8 hours after the period of initial heavy rain. The length of time from the leading edge to peak storm inflow was about 0.5 to 2 hours. The typical flow period of the Debris Basin, System A and System B was 30-40 hours. The magnitude of the peak was proportional to the rainfall intensity and amount.

4. System C peak flows are offset from the Station K-2 peaks by 6 to 10 hours. The System C hydrograph is generally wider, with a smaller peak and a long tail indicating an extended discharge period of several days after each storm.

5. Due to the operation of floodwater bypass gates at Newark Blvd. and an upstream flow diversion berm, low-to-moderate in-channel flows were routed to the DUST Marsh. However, peak flows typically overtopped the diversion berm and bypassed out the flood gates. In comparing system design capacity and observed flows, the DUST Marsh experienced 32 to 54 percent of its total handling capacity.

6. Based on dye-study results during peak flow conditions, the main stormwater travel time was 17 to 19 ft/hr between Station K-2 and Stations A-2 and B-2, and over 32 ft/hr between K-2 and C-2.

Dry Season Water Quality

1. High summer evapotranspiration rates and probable groundwater seepage caused a 200 to 300 percent increase in electrical conductivity and total dissolved solids in the marsh.

2. High seasonal primary productivity lead to decreases in nitrate-nitrogen and ortho-phosphate levels. Algal productivity caused higher chlorophyll 'a' levels and corresponding increases in total suspended solids and BOD from decaying algal cells.

3. Zinc and manganese concentrations decreased from wet season to dry season due probably to adsorption onto particulate matter and sedimentation.

Groundwater Conditions

1. The DUST Marsh site is underlain by a shallow perched aquifer that occurs from 0 to 3 ft below the ground surface. Groundwater surfaces during the winter and spring months where the ground elevation is below +3.0 ft MSL. The deep channels and ponds that drop down to -2.0 ft elevation may also intercept the shallow perched aquifer.

2. Two separate groundwater cells appear under the DUST Marsh: (1) a fresh-to-brackish cell under Systems B and D; and (2) a saline cell under the western end of System A and all of System C exhibiting high TDS, EC and chlorides.

3. Nutrient levels were generally low in groundwater except under System D at the eastern edge of the Marsh site. Probably due to high fertilization and heavy irrigation practices in the adjacent agricultural area, groundwater nitrates were as high as 28 mg/l and phosphate reached 0.4 mg/l.

Development of Plant Communities

1. The recently-constructed overland flow area is at an intermediate development stage. During the first two years after construction, accumulated salts were leaching from the soils and several salt-tolerant plant species such as pickleweed, salt grass, alkali-bulrush and fat hen were found.

2. Alkali bulrush was dominant in System B during 1984-85, but gave way to marshgrass (*Heleochloa* sp.) in 1986. The gradual invasion of cattail (*Typha* sp.) into this area indicates that repeated inundation and water movement is washing excess salts from the soil and providing a favorable environment for plant species with mild salt tolerances.

7. Due to the large storage volume within the DUST Marsh, stormwater volumes from low-to-moderate sized storms were insufficient to displace the pre-storm storage volume. Typically one or more subsequent storm cycles were required to generate enough runoff volume to displace the previous storm runoff. Thus, stormwater residence time would be dependent, in most cases, upon the interval until the next storm or storms.

8. Runoff from the Ardenwood Development was insufficient to drive P-Line flows through the DUST Marsh. To the contrary, System C discharged to the P-Line channel throughout the entire season with the flow rate governed by the volume of backwater in the P-Line channel.

Stormwater Quality

1. The treatment cycle in the marsh system spans several storms, with no one storm providing a complete picture of pollutant loading, system processing and treated effluent.

2. The accumulation of loadings and discharge levels from many storms would account for the prolonged treatment cycle and provide a more complete picture of the marsh treatment function over an entire winter storm season.

3. Salinity increases of 300 percent through the marsh system are probably due to intrusion of shallow saline groundwaters and leaching of saline soils.

4. Indications for nutrient reduction were good: 10 to 15 percent reduction in ammonia-nitrogen and nitrate-nitrogen and 50 percent in phosphate and total phosphorus.

5. Heavy metals were attenuated by the marsh system, except manganese which may be augmented by various internal and external sources.

6. An apparent reduction in total suspended solids (up to 45 percent) occurred through the marsh system.

7. The water quality results are not indicative of final system performance since parts of the marsh, such as the overland flow area in System B, are only 30 to 40 percent vegetated and will require another two to three years to reach a fully-vegetated state and an optimum treatment potential.

3. At the current rate of succession, the overland flow area in System B will probably become fully-vegetated in 2-3 years. The dominant vegetation will probably be Typha in the low-elevation parts, gradating to Scirpus and marshgrass in the seasonally-dry areas.

4. Experimental planting to extend or accelerate marsh vegetation range requires consideration of appropriate growth conditions such as salinity and water depth, as well as external factors such as wildlife grazing pressure and detrimental effects of wind, waves and water currents.

5. Seed planting of alkali-bulrush is suitable mainly for areas with confined cells because wind-induced water movements will transport the seeds toward the windward shore. Sprig planting of alkali bulrush can be successful, but is labor intensive. Observance of maximum water depths and periods of seasonal flooding are important controlling factors for plant growth.

ENVIRONMENTAL FATE OF POLLUTANTS

A summary of heavy metals concentrations in soils vegetation and fish tissue is presented in Table 41. The conclusions for each parameter are presented below:

Soil and Sediment

1. The DUST Marsh exhibits saline (EC > 4 mmhos/cm) and sodic (15% exchangeable-Na) soils due to historical inundation with salt-laden waters and inadequacy of leaching, together with the presence of seasonally high water tables and high evaporation rates.

2. Soils within the recently-constructed (1983) Systems A and B are not yet fully-developed as evidenced by lower cation exchange capacity and organic carbon levels than the well-developed K-Line channel or System C.

3. High clay content in soils, such as that found in System C and under Typha vegetation cover, regulates CEC and movement of nutrients and organic carbon. Increasing clay content also correlates with greater levels of copper, manganese and zinc fixed by chemical interactions onto the fine particulate matter.

4. DUST Marsh soils typically have a silty clay loam and silty clay texture due to the long-term deposition of silt and clay particles from historic flooding.

5. Nitrate-nitrogen and total nitrogen (TKN) levels were relatively high in the soil samples due to external inputs and internal plant cycling activities. Available-P, as measured by ortho-phosphate, was proportionately low indicating binding to soil particles or uptake by plant metabolism.

TABLE 41. SUMMARY OF HEAVY METAL DATA BY SYSTEM[a]

System	Chromium Soil	Chromium Plant	Chromium Pond Sediment	Chromium Fish Liver*	Copper Soil	Copper Plant	Copper Pond Sediment	Copper Fish Liver*
K-1	110	1.9-52	—	—	26	4.7-19	—	—
K-2	140	2.1-15	—	—	37	2.6-9.3	—	—
System A	120	3.3-64	—	nd-.57	36	1.8-15	—	11-14
System B	140	2.5-62	67	1.0-3.0	32	4.0-2.0	16	9.0-25
System C	170	1.9-7.6	—	.15-2.8	44	3.0-1.2	—	5.4-8.2

System	Lead Soil	Lead Plant	Lead Pond Sediment	Lead Fish Liver*	Managanese Soil	Managanese Plant	Managanese Pond Sediment	Managanese Fish Liver*
K-1	29	4.8-16	—	—	29	36-54	—	—
K-2	21	2.4-9.0	—	—	880	122-803	—	—
System A	17	4.4-9.5	—	<0.1-.13	560	116-893	—	9.1-9.5
System B	16	4.5-17	9.4	<0.1-9.0	510	85-1200	(255)	6.4-44
System C	45	3.4-6.2	—	.10-.37	1300	283-860	—	8.3-12

System	Nickel Soil	Nickel Plant	Nickel Pond Sediment	Nickel Fish Liver*	Zinc Soil	Zinc Plant	Zinc Pond Sediment	Zinc Fish Liver*
K-1	84	nd	—	—	59	25-81	—	—
K-2	130	2.9-12	—	—	78	6.9-28	—	—
System A	120	4-43	—	<0.1	78	13-42	—	44-182
System B	110	4-47	(55)	<0.1	66	8-30	35	33-200
System C	130	2.9-7.1	—	<0.1	100	11-41	—	26-39

nd = not detectable

a Mean values in mg/kg dry weight, values in ( ) are estimates

* Estimated dry weight concentration based on average 70% moisture in fish tissue

6. Copper, lead, manganese, and zinc concentrations were relatively high in marsh samples and appeared to correlate with high clay content. Nickel, cadmium and selenium accumulation did not appear to be significant.

Heavy Metals in Vegetation

1. Heavy metals concentrations in vegetation generally followed a pattern of greatest relative uptake in plant roots with decreasing levels in the leaf and seed tissue. Generally, soil root concentrations were less than half of the surface soil amounts and leaf and seed levels were one-half to one-fourth of the root amounts. The exceptions to these levels are noted below:

2. Chromium uptake in System A and B *Typha* seed parts (62 to 64 mg-Cr/kg-dry plant weight) was 4 to 20 times higher than root or leaf parts. The seed parts accumulated up to 47 percent of the background soil concentration.

3. Copper uptake in *Scirpus* and *Typha* was typically highest among root parts (19-20 mg-Cr/kg-dry plant weight) and reached 50-60 percent of the background soil concentration. Leaf and seed concentrations were about equal -- reaching 25 to 65 percent of the root concentrations with *Typha*; seed levels generally higher than leaf levels.

4. Lead uptake was highest within System B. *Scirpus* root and leaf tissue measured 9.2 to 11.4 mg-Pb/kg-dry plant weight -- reaching 67 percent of the background soil concentration. *Typha* root and leaf tissue measured 13 to 17 mg-Pb/kg-dry plant weight -- reaching 106 percent of the background soil concentration.

5. Manganese uptake was consistently highest within leaf tissue for both species with statistically significant uptake associated with *Typha*. Leaf tissue in *Typha* took up 447 to 1200 mg-Mn/kg-dry plant weight -- reaching 34 to 185 percent of the background soil level. Manganese is an important plant micronutrient and appears to be heavily used by *Typha*.

6. Nickel uptake in *Scirpus* and *Typha* was greatest among root parts with the highest observed levels in System A and B *Typha* (43-47 mg-Ni/kg-dry plant weight) -- reaching 43 percent of the background soil concentration. Leaf and seed concentrations were about equal -- ranging from not detectable to 8.7 mg-Ni/kg-dry plant weight.

7. Zinc uptake in *Scirpus* and *Typha* was greatest among root parts with the highest observed levels in System K-1 *Scirpus* (81.3 mg-Zn/kg-dry plant weight) -- reaching 105 percent of the background soil concentration.

8. Overall, Typha exhibits a greater ability to accumulate heavy metals than Scirpus. Metal accumulations appear to be highest within Systems A and B -- areas with comparatively lower pH and probably higher manganese and zinc solubility. In comparisons of total metal uptake per m^2, Typha plots typically contain 2 to 4 times higher metal loadings than Scirpus due to higher unit biomass and differential uptake rates. Based on reported studies, Typha may have a unique physiology that confers a high tolerance to heavy metals -- possibly through a cell wall metal precipitation mechanism.

9. Short-term or new-growth bioaccumulation of chromium, copper, lead, nickel and zinc was significant in Scirpus root tissue and various Typha parts. Metals concentrations in mixed-age or mature stands were generally lower indicating either lower uptake rates or re-release of metals from aging plant material. Manganese uptake appeared to be continuous through all age stands and long-term bioaccumulation in mature stands, particularly Scirpus, was significant.

Heavy Metals in Fish

1. Blackfish and carp liver samples exceed the 85% Elevated Data Level (EDL) in Systems A, B and C for chromium, copper, lead and zinc. Because the EDL does not include liver findings from these species, the significance of the EDL guideline needs to be evaluated against more data from the same species. Cadmium, nickel and selenium concentrations were not significant in fish tissues.

2. Chromium levels in gambusia were higher than values reported in other studies. However, when compared to the South Marsh -- which is similar to the DUST Marsh but with limited urban runoff contribution -- chromium concentrations were at the same level for gambusia and lower for DUST Marsh sculpin.

3. Blackfish and carp accumulated copper in liver tissue at noticeable levels (5.4 to 25 mg-Cu/kg-wet liver weight) which were six to seven times higher than in the flesh. Copper levels in gambusia and sculpin were lower than values reported in other studies and comparable to levels found in the control South Marsh. Carp and blackfish liver, as well as gambusia-whole body, appear to be able to accumulate copper up to the ambient sediment concentration.

4. Stickleback and gambusia consistently accumulated lead in body tissues at higher levels (0.15 to 1.5 mg-Pb/kg-wet weight) than other species. Lead levels in DUST Marsh gambusia were also three to four times higher than those reported in other studies. However, lead levels in gambusia and sculpin were lower than those found in the control South Marsh.

5. Manganese concentrations in DUST Marsh fish were two to five times greater than South Marsh levels. This may be related to the high manganese levels found in DUST Marsh soils and vegetation; and the prevalence of seasonal brackish water.

6. Carp liver samples from Systems A and B; and gambusia samples from System B showed relatively high zinc concentrations compared with other marsh species. Carp liver concentrations were 28 times greater than the flesh and about five times higher than the sediments. Zinc levels in gambusia and sculpin were lower than values reported in other studies and comparable to or less than levels found in the control South Marsh.

7. Blackfish and carp livers exhibited long-term bioaccumulation of chromium, copper and lead. Carp also accumulated lead and zinc in the more mature and larger fish specimens. Due to lead concentration in fish flesh from these two species that exceed the Median International Standard, regular human consumption of fish from this marsh would not be advisable. The source of the metal contamination appears to be the sediments. Since these metals concentrations are found in gambusia and stickleback from both the DUST Marsh and the control South Marsh, additional factors such as saline soil conditions and/or groundwater intrusion may be involved. These other factors may affect ambient metal levels to a greater extent than stormwater contributions.

EVALUATION OF DUST MARSH SYSTEM AND TREATMENT PERFORMANCE

1. The DUST Marsh is a relatively young marsh system that has not yet reached equilibria between upland and wetland soils or between marsh sediments and overlying water. A climax vegetative state has not yet been achieved on Systems A and B. These are important considerations in evaluating overall system performance.

2. The DUST Marsh soils have historically experienced various conditions of flooding, saltwater intrusion and agricultural irrigation/leaching practices. The saline and sodic nature of these local soils have led to high mineral, nutrient and heavy metal background concentrations. Evaluation of stormwater pollutant contributions to marsh soils and sediments should be viewed in this overall context.

3. Stormwater inundation and flow over the new marsh system has had the apparent effect of drawing out accumulated salts and materials, as well as loosening up and suspending particulate matter from the soils. Mobilization of fine particulates in turn, liberates bound nutrients and heavy-metals. Thus, in the first few years of operation, we theorize that marsh soils should decrease in salinity while surface waters should exhibit increased salinity and soil-originated mineral, nutrient and heavy metal loadings.

4. The quantification and statistical verification of changes in soil parameters were difficult to perform as the variation within sub-systems was often greater than the variance between systems. However, the data on plant species succession provided an indirect basis for evaluating changes in soil conditions. During the first two years of operation, highly salt-tolerant plant species - such as pickleweed, salt bush and

fat hen were observed colonizing the new marsh site. In Spring 1986, after three years of stormwater inflow, the above three plant species have vanished and been replaced by mildly salt-tolerant species such as alkali bulrush, cattail and marshgrass. The shift in species implies a significant decrease in salt and mineral concentrations and provides a qualitative verification of the change in soil conditions.

5. Increases in water salinity and other parameters were noted during the 1985-86 wet season that did not correlate with predicted marsh treatment performance and may indicate unique conditions associated with the marsh site. Specifically, salinity (electrical conductivity), dissolved solids (TDS), organic matter (BOD), organic nutrients (Kjeldahl nitrogen and total phosphorus) oil and grease and selected heavy metals (copper, manganese, nickel and zinc) increased within the newly-constructed marsh systems.

   In light of the previously-mentioned relationship between developing marsh soils and overlying surface waters, increased conductivity and dissolved solids appear to be directly related to leaching of saline and sodic soils rather than treatment performance. The treatment function on the other parameters is less clear. Increases in oil and organic compounds may be due to the release of interbedded organic material deposited during past flooding and to agricultural conditions. Of the heavy metals mentioned, manganese frequently occurs in saline soils, the other metals are often bound to the particulate matter and governed by local soil conditions.

6. As the DUST Marsh system matures, the following conditions are anticipated: (1) the development of more complete and dense vegetative cover on the overland flow area of System B and the perimeter of System A; (2) stabilization of marsh sediments; (3) establishment of an equilibrium for dissolved/suspended material between the soil-water interface; and (4) improved water treatment performance related to a combination of the first three conditions.

   Indications of positive treatment performance in a mature marsh system can be drawn from the loading data on System C. This system was not subject to excavation and subsequent inundation as were Systems A and B. The bottom sediments were dredged from the System C channel and almost all of the established wetland vegetation remained intact within the site. During Winter 1985-86, System C efficiently reduced the incremental BOD, organic phosphorus, oil and grease and all heavy metals except manganese generated from Systems A and B.

   Overall, the DUST Marsh was effective in the reduction of suspended solids, inorganic nitrogen, phosphorous, cadmium and lead regardless of system. As the marsh becomes more established, the differences in treatment levels between Systems A, B and C due to design variations will become more apparent. A follow up study in three to five years is indicated to verify the projected trend in system performance.

7. Alkali bulrush (Scirpus robustus) and cattail (Typha latifolia) demonstrated significant uptake potentials for all heavy metals. Overall, cattail exhibited the greatest removal potential due to a combination of higher uptake rates in the leaf and seed tissues, greater storage in root and rhizomes and the highest biomass/M^2 (two to three times more than bulrush). Scirpus uptake levels were generally one-third to one-half of Typha levels and are important in areas where Typha is sub-dominant.

8. In terms of food chain effects, Scirpus provides a higher food value for wildlife than Typha. Evidence of grazing on Scirpus leaf tissue by waterfowl and deer was found in the DUST Marsh, however, bulrush seed is also an important food source for resident and seasonal waterfowl. Bulrush seed levels of copper, lead and zinc approached cattail seed levels, which were generally within the 'normal' range of reported literature. Cattail, which took up high metal concentrations in the root, leaf and particularly seed parts, provides marginal food value. Geese have been known to forage on cattail roots and rhizomes, however, leaf and seed parts are generally overlooked by wildlife. In a mature cattail stand, the rhizomes are often thickly matted and difficult to access and harvest.

9. In the evaluation of a biological removal medium for heavy metals in a wetland, Typha appears to be ideal. Given the right conditions, cattails are able to grow vigorously, develop substantial biomass and bioaccumulate heavy metals beyond ambient levels. Unfortunately, cattails can grow so thickly as to inhibit water circulation and severely reduce habitat diversity. In flood control channels and some park and recreation areas, dredging and plant harvesting have been used to control cattail overgrowths. Harvesting of cattail plant material could also serve to remove the stored heavy metals. Periodic removal of cattail stands, thus, could serve the multiple purpose of improving water circulation, renewing plant growth in old cattail stands and increasing the pollutant uptake capacity of a wetland system. The harvested material could be composted and used as a soil amendment to non-food crops and landscaping similar to current practices for recycling sewage sludge.

10. Blackfish and carp liver specimens exhibited elevated toxic metal pollutant levels compared to a range of many freshwater fish species analyzed during the last 10 years in the Toxic Substances Monitoring Program conducted by the California Department of Fish and Game. More studies are indicated to determine correlations between metal content in liver versus flesh tissues for these species and to determine the range of heavy metal occurrence in blackfish and carp from other locations.

11. Composited stickleback and gambusia whole body samples occasionally exhibited metal concentrations on the magnitude of blackfish and carp liver samples. This draws attention to possible elevated metal concentrations in these species. However, samples of these same species from the control South Marsh at Coyote Hills show similar

levels of metals concentrations. This indicates a possible relationship between local soils and other environmental factors that may influence fish metals concentrations. Further study would be required to draw conclusions about direct or indirect relationships.

RECOMMENDATIONS

While significant knowledge has been gained from the DUST Marsh project, it has been become apparent that some important questions have not been fully answered. These questions remain unresolved primarily because the project was conducted in a newly constructed marsh with large areas of newly exposed soil and with a vegetative cover that is not yet well established. Consequently, the following recommendations are offered.

1. The use of wetlands to treat urban stormwater runoff should be limited to constructed wetlands. Because the degree and significance of bioaccumulations of pollutants in the food chain is as yet unclear, such risks should not be imposed upon natural wetlands. These risks are more appropriately taken in artificial wetlands where conditions may be better controlled and periodic maintenance such as dredging or harvesting of vegetation would be acceptable.

2. Wetlands established for urban runoff treatment should be sited with due consideration of existing conditions. As evidenced in the DUST Marsh, previous land use practices, such as farming, may leave higher than normal concentrations of various "pollutants" in the soil. When this soil is exposed in a newly constructed wetland, these pollutants may actually be released into the stormwater until the wetland is fully stabilized. Similarly, pockets of brackish groundwater, present in shoreline areas, may actually contribute metals (manganese in the DUST Marsh) and other salts to the relatively fresh stormwater.

3. Further research should be conducted on the accumulation of various pollutants in the food chain. We recommend that heavy metals (particularly cadmium, chromium, lead and zinc) and toxic hydrocarbons be monitored in plants, invertebrates and fish for a period of several years in a wetlands treatment system. This is necessary to determine the significance of the amounts of metals found in fish livers in this study.

4. The current DUST Marsh is not an established, mature wetland. Another two to three years of plant growth will be required before the standing vegetation crop can be considered heavy or typical. Since stormwater pollutant removal in a wetland is tied to the vegetation, we can expect future improvement in treatment performance. We thus recommend that a follow-up study on wetlands treatment at the DUST Marsh be commenced in two years. The study should focus on selected pollutants that would be considered harmful

in San Francisco Bay nearshore waters -- lead, chromium, copper, zinc, cadmium and toxic hydrocarbons (a subset of oil and grease).

5. Finally, this study began with the hypothesis that wetlands could provide water quality improvements to urban stormwater runoff. We had demonstrated that, in general, the quality of water passing through the DUST Marsh improved. We remain convinced that as the marshland vegetation leaves the transitional stage and becomes fully established, water treatment capability will significantly improve. Thus, ABAG still recommends use of artificial wetlands as a viable urban runoff pollution control measure.

APPENDIX A - REFERENCES

Adrian, W. J. 1971. A new wet digestion method for biological material utilizing pressure. Atomic Absorption Newsletter 10(4):96.

Agemian, H., D. P. Sturtevant and K. D. Austen. 1980. "Simultaneous acid extraction of fixed trace metals from fish tissue by hot block digestion and determination by Atomic Absorption spectrophotometry", Analyst 105:125.

American Public Health Assoc. 1985. Standard Methods for the Examination of Water and Wastewater. Fifteenth Edition. American Public Health Assoc., Wash. D.C.

American Society for Testing Materials, 1982. Annual Book of ASTM Standards. American Society for Testing Materials.

Association of Bay Area Governments. 1979. Treatment of stormwater runoff by a marsh/flood basin - Interim Report. Association of Bay Area Governments, Oakland, California.

Barbour, M. G., J. H. Burk, and W. D. Pitts. 1980. Terrestrial Plant Ecology. Benjamin/Cummings Publ. Co., Inc. Menlo Park, California.

Baudo, R. and P. G. Varini. 1976. Copper, manganese and chromium concentrations in five macrophytes from the delta of River Toce (Northern Italy). Memorie dell' Istituto di Idrobiologia 33:305-324.

Blaney, H. F. and D. C. Mucket. 1955. Evaporation and evapotranspiration investigations in the San Francisco Bay Area. Transactions, American Geophysical Union 36(5):813.

Boyd, C. E. 1970. Vascular Aquatic Plants for Mineral Nutrient Removal from Polluted Waters. Econ. Bot. 24(1):95.

Buchauer, M. J. 1973. Contamination of soil and vegetation near a zinc smelter by zinc, cadmium, copper and lead. Environ. Sci. Technol. 7:131-135.

California State Water Resources Control Board. 1985. Toxic Substances Monitoring Program - 1984. California State Water Resources Control Board Water Quality Monitoring Report No. 86-4WQ.

Carbonneau, M. and J. L. Tremblay. 1972. The role of Scirpus americanus (Pers.) in depolluting waters contaminated with heavy metals (in French). Naturaliste Canadien 99(5):523-532.

Chan, E., T. A. Bursztynsky, N. Hantzsche and Y. J. Litwin. 1982. The use of wetlands for water pollution control. EPA - 600/52-82-086.

Chan, E. and G. Silverman. 1982. Demonstration of urban stormwater treatment - Project Report No. 1. Association of Bay Area Governments, Oakland, California.

Chase, E. B. and F. N. Payne. 1970. Selected Techniques in Water Resources Investigations. Geological Survey Water -- Supply Paper 1892. U.S. Govt. Printing Office, Wash. D.C. 20402.

Collins, Josh. Personal communication. August 1985.

Cox, G. W. 1981. Laboratory Manual of General Ecology, Fourth Edition. Wm. C. Brown Co., Publishers, Dubuque, Iowa.

Crampton, Beecher. 1974. Grasses in California. University of California Press, Berkeley. 178 pp.

Environmental Protection Agency. 1979. Methods for chemical analysis of water and waste. EPA 600/4-79-020.

Environmental Protection Agency. 1984. "Test Methods for Evaluating Solid Waste - 2nd Edition" EPA SW846. April 1984.

Estabrook, George F., David W. Burk, Dennis R. Inman, Peter B. Kaufman, James R. Wells, John D. Jones and Najati Ghosheh. 1985. Comparison of heavy metals in aquatic plants on Charity Island, Saginaw Bay, Lake Huron, U.S.A., with plants along the shoreline of Saginaw Bay. Amer. J. Bot. 72(2):209-216.

Fetter, C. W., W. E. Sloey and F. L. Spangler. 1978. Use of a natural marsh for waste water polishing. Journal Water Pollution Control Federation 50(2):290.

George, H. 1963. Planting alkali bulrush for waterfowl food. California Department of Fish and Game, Game Management Leaflet No. 9, 9 pp.

Harvey, Tom. Personal communication. August 1985.

Hausenbuiller, R. L. 1972. Soil Science, Principles and Practices. Wm. C. Brown Co. Publishers, Dubuque, Iowa.

Kaushik, D. K. 1963. The influence of salinity on the growth and reproduction of marsh plants. Utah State University. Logan, Utah. PhD Dissertation. 122 pp.

Kilpatrick, F. A. 1970. Dosage requirements for slug injections of Rhodamine BA and WT Dyes. Geological Survey Research, U.S. Geological Survey Prof. Paper 700 B, B250-253.

Klopatek, J. 1978. Nutrient dynamics of freshwater riverine marshes and the role of emergent macrophytes. In: Freshwater Wetlands: Ecological Processes and Management Potential. R. E. Good, D. F. Whigham and R. L. Simpson (eds). Academic Press. New York, N.Y.

Krenkel, P. A. (ed). 1975. Heavy Metals in the Aquatic Environment: Proceedings of the International Conference at Nashville, Tennessee, 1973. Pergamon Press, Elmsford, N.Y.

Leonard, C. M. 1971. The determination of copper in fish tissue by atomic absorption spectrophotometry. Atomic Absorption Newsletter 10:84.

Mall, Rolf. 1969. Soil-water relationships of waterfowl food plants in the Suisun Marsh of California. California Department of Fish and Game, Wildlife Bulletin No. 1.

Mathis. B. J. and N. R. Kevern. 1975. Distribution of mercury, cadmium, lead and thallium in an eutrophic lake. Hydrobiologia 46(2-3):207-222.

McNaughton, S. J., T. C. Folsom, T. Lee, F. Park, C. Price, D. Roeder, J. Schmitz, and C. Stockwell. 1974. Heavy metal tolerance in Typha latifolia without the evolution of tolerant races. Ecology 55:1163-1165.

Morgan, Norm, California Department of Fish and Game Water Pollution Control Laboratory Chemist. Personal Communication. February 1986.

Mudroch, A. and J. A. Capobianco. 1978. Study of selected metals in marshes on Lake St. Clair, Ontario. Arch. Hydrobiol. 84(1):87-108.

Mudroch, A. and J. A. Capobianco. 1979. Effects of mine effluent on uptake of Co, Ni, Cu, As, Zn, Cd, Cr and Pb by aquatic macrophytes. Hydrobiologia 64(3):223-231.

Mueller-Dombois, Dieter, and Heinz Ellenberg. 1974. Aims and Methods of Vegetation Ecology. John Wiley and Sons, New York.

Nichols, D. R. and N. A. Wright. 1971. Preliminary map of historic margins of marshlands, San Francisco Bay, California. U.S. Geological Survey Basic Data Contributions No. 9.

Page, A. L. (Ed.) 1982. Methods of Soil Analysis: Part 2. Amer. Soc. Agronomy 1982. No. 9 (Part 2) in the series Agronomy.

Prentki, R. T., T. D. Gustafson and M. S. Adams. 1978. Nutrient movements in lakeshore marshes. In: Freshwater Wetlands: Ecological Processes and Management Potential. R. E. Good, D. F. Whigham and R. L. Simpson (eds). Academic Press, New York, N. Y.

Ray, S. and W. White. 1976. Selected aquatic plants as indicator species for heavy metal pollution. J. Environ. Sci. Health All(12):717-725.

Seidel, K. 1976. Macrophytes and water purification. In: Biological Control of Water Pollution. J. Tourbier and R. W. Pierson, Jr. (eds). University of Pennsylvania Press, Philadelphia, PA.

Silverman, G. 1984. Demonstration of urban stormwater treatment - project report No. 2: marsh design considerations and specifications. Association of Bay Area Governments, Oakland, California.

Spangler, F. L., W. E. Sloey and C. W. Fetter. 1976. Artificial and natural marshes as wastewater treatment systems in Wisconsin. In: Freshwater Wetlands and Sewage Effluent Disposal, D. L. Tilton, R. H. Kadlec and C. J. Richardson (eds). University of Michigan, Ann Arbor, Michigan.

Statistical Package for the Social Sciences. 1975. Second Edition. McGraw Hill, New York. 675 pp.

Statview 512+, 1986. BrainPower, Inc. Calabasas, California

Stenstrom, M. and Gary Silverman. 1982. Oil and Grease in Stormwater Runoff. The Association of Bay Area Governments, Oakland, California.

Stephenson, M., G. Turner, P. Pope, J. Colt, A. Knight and G. Tchobanoglous. 1980. The use and potential of aquatic species for wastewater treatment, Appendix A: The environmental requirements of aquatic plants. California State Water Resources Control Board Publication No. 65.

Stowell, R., R. Ludwig, J. Colt and G. Tchobanoglous. 1980. Toward the rational design of aquatic treatment systems. Presented at ASCE Spring Convention, April 14-18, 1980. Portland, Oregon.

Stumm, W. and J. L. Morgan. 1970. Aquatic Chemistry. Wiley-Interscience, New York.

Taylor, G. J., and A. A. Crowder. 1983. Uptake and accumulation of heavy metals by *Typha latifolia* in wetlands of the Sudbury, Ontario region. Canadian J. Botany 61(1):63-73.

Turner Designs. 1980. Fluorometric Facts -- Flow measurements in sanitary sewers by dye dilution. Turner Designs, Mountain View, California. 10 pg.

United States Salinity Laboratory Staff. 1954. Diagnosis and Improvement of Saline and Alkali Soils. U. S. Department of Agriculture Handbook No. 60, reprinted August 1969.

Varenko, N. I. and V. T. Chuiko. 1977. Role of higher aquatic plants in the migration of manganese, zinc, copper and cobalt in the Dneprodzerzhinsk Reservoir. Hydrobiological J. 7:45-48.

Wells, J. R., P. B. Kaufman and J. D. Jones. 1980. Heavy metal contents in some macrophytes from Saginaw Bay (Lake Huron, USA). Aquatic Botany 9:185-193.

Welsh, P. and P. Denny. 1976. Waterplants and the recycling of heavy metals in an English lake. Trace Substances in Environmental Health 10.

Wilson, James F. 1968. Time of Travel Measurements and Other Applications of Dye Tracing. Intl. Assoc. Sci. Hydrol. Pub. No. 76 (1968).

APPENDIX B

STORMWATER DATA

TABLE B-1. 13 NOVEMBER 1984 STORM SUMMARY

RAINFALL

Gauge location	Start time	Total rainfall	Duration	Days since last storm
Union City Fire Station	0945 Nov 12	1.53	12.0 hr	2
Coyote Hills Park	0945 Nov 12	1.38	12.0 hr	2

SAMPLE PERIOD

Station	Start time	Stop time
K-1	0005 Nov 13	1300 Nov 13
K-2	0040 Nov 13	0700 Nov 13
A-2	0105 Nov 13	1109 Nov 13
B-2	0110 Nov 13	1119 Nov 13
C-2	0130 Nov 13	1135 Nov 13

REGULAR ANALYTICAL RESULTS[a]

Station	Time, hours	pH, unit	Conductivity umhos/cm	TDS	TSS	5-day BOD	Oil & Grease	Fecal Coliform, MPN/100 ml
K-1	0005	7.44	110	89	290	3.6	1.6	≥ 2,400
K-1	0645	7.46	240	150	2,900	1.3	1.0	≥ 2,400
K-1	1030	7.62	180	120	1,300	1.8	1.2	≥ 2,400
K-2	0040	7.34	700	430	290	2.4	0.3	≥ 2,400
K-2	0700	7.32	280	160	1,200	2.5	0.4	≥ 2,400
K-2	1030	7.28	310	220	1,200	2.2	0.3	1,600
A-2	0105	7.45	1,660	1,000	92	4.3	0.8	≥ 2,400
A-2	0715	7.50	1,360	790	130	3.4	0.5	≥ 2,400
A-2	1109	7.38	1,070	570	170	3.1	0.7	540
B-2	0110	7.51	1,540	1,000	85	3.7	0.3	≥ 2,400
B-2	0720	7.57	640	390	260	3.1	1.1	≥ 2,400
B-2	1119	7.61	580	350	360	2.7	0.7	540
C-2	0130	7.48	1,530	910	82	3.7	1.3	350
C-2	0740	7.49	1,600	970	84	3.5	0.5	540
C-2	1135	7.51	1,640	1,000	72	4.0	1.2	540

Station	Time, hours	Ammonia N	Nitrate N	Kjeldahl N	Ortho P	Total P	Cd	Cr	Cu	Pb	Mn	Ni	Zn
K-1	0645	0.23	2.3	3.1	0.32	4.2	< 0.002	< 0.005	0.01	< 0.005	0.05	< 0.03	0.06
K-1	1030	0.25	1.2	1.1	0.19	1.6	< 0.002	< 0.005	< 0.01	0.008	0.03	0.05	0.02
K-1	1300	0.24	1.3	0.7	0.22	1.7	< 0.002	< 0.005	0.03	< 0.005	< 0.02	0.06	< 0.01
K-2	0700	0.45	2.0	2.8	0.30	0.74	< 0.002	0.006	0.01	0.006	< 0.02	< 0.03	0.02
K-2	1030	0.48	2.5	2.5	0.40	3.1	< 0.002	0.008	< 0.01	< 0.005	< 0.02	< 0.03	< 0.01
K-2	2440	0.53	3.1	3.1	0.22	0.64	< 0.002	< 0.005	0.01	< 0.005	< 0.02	0.04	0.02
A-2	0715	0.32	1.4	1.8	0.12	0.19	< 0.002	< 0.005	0.01	< 0.005	0.15	0.04	< 0.01
A-2	1109	0.29	1.8	1.4	0.15	0.32	< 0.002	< 0.005	0.01	< 0.005	0.14	< 0.03	0.01
A-2	0105	0.35	0.82	2.2	0.06	0.37	< 0.002	< 0.005	0.01	< 0.005	0.22	0.06	< 0.01
B-2	0720	0.31	2.6	1.1	0.21	0.92	< 0.002	< 0.005	< 0.01	< 0.005	< 0.02	< 0.03	< 0.01
B-2	1119	0.28	2.3	1.8	0.25	1.3	< 0.002	< 0.005	< 0.01	< 0.005	0.02	< 0.03	< 0.01
B-2	0110	0.35	0.85	2.1	0.08	0.12	< 0.002	< 0.005	0.01	< 0.005	0.10	< 0.03	0.01
C-2	0740	0.23	0.96	1.6	0.10	0.39	< 0.002	< 0.005	0.01	0.021	0.53	0.04	< 0.01
C-2	1135	0.47	0.93	0.9	0.07	0.32	< 0.002	< 0.005	0.01	< 0.005	0.46	< 0.03	< 0.01
C-2	0130	0.28	1.0	1.9	0.10	0.37	< 0.002	< 0.005	0.07	< 0.005	0.46	< 0.03	0.02

[a] mg/l except as noted

TABLE B-2. 27 NOVEMBER 1984 STORM SUMMARY

RAINFALL

Gauge location	Start time	Total rainfall	Duration	Days since last storm
Union City Fire Station	1310 Nov 27	.87	9 hrs	1
Coyote Hills Park	1310 Nov 27	.51	9 hrs	1

SAMPLE PERIOD

Station	Start Time	Stop Time
K-2	1715 Nov 27	1555 Nov 28
K-3	0830 Nov 28	1551 Nov 28
A-2	1735 Nov 27	1609 Nov 28
B-2	1743 Nov 27	1612 Nov 28
C-2	1758 Nov 27	1626 Nov 28

REGULAR ANALYTICAL RESULTS[a]

Station	Date	Time, hours	pH, unit	Conductivity umhos/cm	TDS	TSS	5-day BOD	Oil & Grease	Fecal Coliform, MPN/100 ml
K-2	11/27	1715	7.89	4,400	2,400	84	2.5	0.5	130
	11/28	0200	7.59	600	310	500	3.2	0.9	≥ 2,400
		1129	7.48	600	320	150	3.3	0.7	≥ 2,400
		1555	7.52	600	350	140	2.5	0.5	≥ 2,400
K-3	11/28	0830	7.57	1,800	1,200	58	3.0	0.9	350
		1551	7.83	2,300	1,400	65	5.9	0.2	220
A-2	11/27	1735	7.80	2,400	1,400	44	4.0	< 0.1	14
	11/28	0245	7.67	2,500	1,500	39	4.7	0.5	170
		1129	7.50	1,200	650	210	4.9	1.0	920
		1609	7.67	1,800	1,100	84	3.8	0.7	1,600
B-2	11/27	1743	7.87	2,300	1,300	36	3.9	< 0.1	11
	11/28	0254	7.82	2,500	1,600	47	3.7	0.6	49
		1140	7.52	660	310	170	3.9	0.8	≥ 2,400
		1612	7.60	950	680	190	3.1	0.6	≥ 2,400
C-2	11/27	1758	7.86	2,300	1,300	56	4.6	< 0.1	31
	11/28	0311	7.71	2,200	1,400	41	5.6	0.6	13
		1157	7.88	2,100	1,400	36	4.4	0.5	33
		1626	7.93	2,400	1,500	30	3.4	0.4	33

Station	Date	Time, hours	Ammonia N	Nitrate N	Kjeldahl N	Ortho P	Total P	Cd	Cr	Cu	Pb	Mn	Ni	Zn
K-2	11/27	1715	0.25	7.8	3.2	0.07	0.28	< 0.002	0.007	0.01	0.006	0.41	0.11	< 0.01
	11/28	0200	0.44	1.9	3.9	0.24	1.5	< 0.002	< 0.005	< 0.01	< 0.005	< 0.02	0.03	< 0.01
		1129	0.24	1.1	2.5	0.20	0.35	< 0.002	0.008	< 0.01	0.010	0.10	< 0.03	< 0.01
		1555	0.18	1.3	2.7	0.19	0.57	< 0.002	< 0.005	< 0.01	< 0.005	0.06	0.05	< 0.01
K-3	11/28	0830	0.31	2.3	3.9	0.15	0.47	< 0.002	< 0.005	< 0.01	< 0.005	0.90	0.05	< 0.01
		1551	0.22	1.7	3.5	0.02	0.42	< 0.002	< 0.005	0.01	< 0.005	0.92	0.08	< 0.01
A-2	11/27	1735	0.45	2.1	2.7	0.02	0.19	< 0.002	< 0.005	0.01	< 0.005	1.2	< 0.03	0.02
	11/28	0245	0.81	2.4	3.0	0.03	0.18	< 0.002	< 0.005	0.01	< 0.005	0.95	< 0.03	< 0.01
		1129	0.95	2.7	2.0	0.16	0.82	< 0.002	< 0.005	0.03	< 0.005	0.42	< 0.03	< 0.01
		1609	0.45	3.1	2.1	0.11	0.38	< 0.002	< 0.005	0.01	< 0.005	0.68	< 0.03	< 0.01
B-2	11/27	1743	0.09	2.1	1.8	0.02	0.18	< 0.002	0.006	0.02	< 0.005	1.1	< 0.03	< 0.01
	11/28	0254	0.33	3.1	2.4	0.03	0.19	< 0.002	< 0.005	0.02	< 0.005	0.68	0.04	< 0.01
		1140	0.28	2.7	3.8	0.20	0.98	< 0.002	< 0.005	< 0.01	< 0.005	< 0.02	0.06	< 0.01
		1612	0.47	2.4	2.7	0.19	0.38	< 0.002	< 0.005	< 0.01	0.013	0.02	0.08	< 0.01
C-2	11/27	1758	0.19	1.4	2.6	0.02	0.21	< 0.002	< 0.005	0.01	< 0.005	2.1	< 0.03	< 0.01
	11/28	0311	0.56	2.0	3.2	0.01	0.17	< 0.002	< 0.005	0.02	< 0.005	2.2	0.03	< 0.01
		1157	0.58	1.7	3.4	0.01	0.16	< 0.002	0.016	0.02	< 0.005	1.9	0.08	< 0.01
		1626	0.46	2.2	2.6	< 0.01	0.14	< 0.002	< 0.005	0.01	< 0.005	1.4	0.03	< 0.01

[a] mg/l except as noted

TABLE B-3. 7 FEBRUARY 1985 STORM SUMMARY

RAINFALL

Gauge location	Start time	Total rainfall	Duration	Days since last storm
Union City Fire Station	Feb 7 2200	1.38 in.	10.0 hr	4
Coyote Hills Park	N/A	N/A	N/A	-

SAMPLE PERIOD

Station	Start Time	Stop Time
K-1	0300 Feb 8	1800 Feb 8
K-2	0407 Feb 8	0650 Feb 9
A-2	0415 Feb 8	0700 Feb 9
B-2	0415 Feb 8	0700 Feb 9
C-2	0430 Feb 8	0730 Feb 9

REGULAR ANALYTICAL RESULTS[a]

Station	Date	Time, hours	pH, unit	Conductivity umhos/cm	TDS	TSS	5-day BOD	Oil & Grease	Fecal Coliform, MPN/100 ml
K-1	2/8	0300	8.30	1,200	840	71	2.5	0.4	7
		0900	7.30	174	120	230	4.4	1.1	≥ 2,400
		1115	7.18	77	66	240	3.0	0.9	≥ 2,400
		1800	7.36	130	95	100	2.0	0.9	≥ 2,400
K-2	2/8	0407	8.46	1,560	910	21	1.1	0.4	17
		0900	8.27	1,440	870	69	1.8	< 0.1	280
		1130	7.55	246	160	160	3.2	0.4	23
		1500	7.35	179	130	140	3.1	0.3	--
	2/9	0030	7.45	177	130	89	2.8	< 0.1	≥ 2,400
		0650	7.68	189	150	79	2.9	0.3	≥ 2,400
A-2	2/8	0415	8.58	262	1,700	57	5.4	1.3	2
		0900	8.26	2,480	1,700	56	5.0	1.4	13
		1145	8.34	2,690	1,700	44	4.9	1.3	5
	2/9	0100	7.96	637	420	88	3.7	1.7	≥2,400
		0700	8.06	578	380	82	3.4	1.7	≥2,400
B-2	2/8	0415	8.43	2,690	1,800	42	4.4	1.6	5
		0900	8.37	2,730	1,700	43	6.0	1.3	2
		1145	8.48	2,390	1,500	51	5.8	1.6	46
	2/9	0100	7.90	554	320	99	2.4	1.7	≥ 2,400
		0700	7.75	453	290	99	2.4	1.3	≥ 2,400
C-2	2/8	0430	8.42	2,980	1,800	50	2.6	1.6	920
		0930	8.37	2,980	1,900	39	2.9	1.4	9
		1145	8.45	3,040	1,900	48	6.2	1.3	13
	2/9	0130	8.35	2,020	1,300	37	3.0	1.8	280
		0730	8.12	1,080	670	61	3.3	1.2	1,600

Station	Date	Time, hours	Ammonia N	Nitrate N	Kjeldahl N	Ortho P	Total P	Cd	Cr	Cu	Pb	Mn	Ni	Zn
K-1	2/8	0300	0.22	3.5	1.2	0.06	0.19	< 0.002	0.006	< 0.01	0.005	0.23	0.04	0.03
		0900	0.25	0.72	0.92	0.19	0.54	< 0.002	0.014	0.01	0.017	0.29	0.03	0.12
		1115	0.25	0.46	1.1	0.17	0.64	< 0.002	0.016	0.01	0.032	0.30	0.04	0.09
		1800	0.50	0.61	1.1	0.22	0.42	< 0.002	0.022	< 0.01	0.025	0.17	0.03	0.06
K-2	2/8	0407	0.89	2.3	0.91	0.02	0.04	< 0.002	< 0.005	0.06	< 0.005	0.04	< 0.03	0.03
		0900	0.52	2.9	1.1	0.07	0.17	< 0.002	< 0.005	< 0.01	< 0.005	0.17	0.03	0.03
		1130	0.18	0.89	--	0.15	0.55	< 0.002	0.013	< 0.01	0.008	0.22	0.04	0.05
		1500	0.40	0.69	0.89	0.16	0.46	< 0.002	0.010	< 0.01	0.011	0.19	< 0.03	0.04
	2/9	0030	0.24	0.75	1.8	0.17	0.39	< 0.002	0.015	< 0.01	0.011	0.14	0.04	0.06
		0650	0.40	0.89	1.1	0.16	0.38	< 0.002	0.015	< 0.01	0.010	0.12	< 0.03	0.04
A-2	2/8	0415	0.26	0.34	1.1	< 0.01	0.18	< 0.002	< 0.005	< 0.01	< 0.005	1.4	0.08	0.02
		0900	0.24	0.37	1.2	< 0.01	0.20	< 0.002	0.006	< 0.01	< 0.005	1.5	< 0.03	0.02
		1145	0.40	1.1	1.5	< 0.01	0.18	< 0.002	< 0.005	0.01	< 0.005	1.5	0.07	0.01
	2/9	0100	0.44	0.74	1.6	0.12	0.30	< 0.002	0.027	< 0.01	0.006	0.23	0.08	0.04
		0700	0.31	0.60	0.93	0.12	0.30	< 0.002	0.005	< 0.01	0.008	0.24	< 0.03	0.04
B-2	2/8	0415	0.36	0.42	1.2	< 0.01	0.24	< 0.002	< 0.005	< 0.01	< 0.005	1.2	< 0.03	0.01
		0900	0.19	0.39	1.1	< 0.01	0.14	< 0.002	< 0.005	0.01	< 0.005	1.4	0.03	0.01
		1145	0.44	0.79	2.1	< 0.01	0.17	< 0.002	< 0.005	< 0.01	< 0.005	1.1	0.03	0.02
	2/9	0100	0.21	2.4	1.3	0.12	0.32	< 0.002	0.010	< 0.01	0.005	0.17	0.03	0.04
		0700	0.18	1.0	1.0	0.15	0.34	< 0.002	0.008	0.01	0.006	0.20	0.05	0.06
C-2	2/8	0430	0.21	0.35	1.1	< 0.01	0.14	< 0.002	< 0.005	0.01	< 0.005	1.2	0.03	0.02
		0930	0.44	0.27	0.98	< 0.01	0.15	< 0.002	< 0.005	< 0.01	< 0.005	1.3	< 0.03	0.02
		1145	0.30	0.37	1.0	< 0.01	0.15	< 0.002	< 0.005	< 0.01	0.006	1.4	0.04	0.08
	2/9	0130	0.16	1.0	0.89	< 0.01	0.11	< 0.002	< 0.005	< 0.01	< 0.005	0.61	0.03	0.03
		0730	0.20	1.27	1.2	0.08	0.26	< 0.002	0.010	< 0.01	< 0.005	0.38	< 0.03	0.03

[a] mg/l except as noted

TABLE B-4. 5 MARCH 1985 STORM SUMMARY

RAINFALL

Gage location	Start time	Total rainfall	Duration	Days since last storm
Union City Fire Station	1030 Mar 5	.80 in.	17.0 hr	0
Coyote Hills Park	N/A	N/A	N/A	-

SAMPLE PERIOD

Station	Start Time	Stop Time
K-1	2254 Mar 5	2240 Mar 6
K-2	2240 Mar 5	2100 Mar 6
A-2	0755 Mar 5	2300 Mar 6
B-2	0755 Mar 5	2300 Mar 6
C-2	1430 Mar 6	0900 Mar 7

REGULAR ANALYTICAL RESULTS[a]

Station	Date	Time, hours	pH, unit	Conductivity umhos/cm	TDS	TSS	5-day BOD	Oil & Grease	Fecal Coliform, MPN/100 ml
K-1	3/5	2254	7.34	238	170	100	10.	2.1	≥ 2,400
	3/6	1250	7.69	260	150	57	5.1	0.7	1,600
		2240	7.39	149	110	63	5.2	1.2	≥ 2,400
K-2	3/5	2240	8.19	1,840	1,200	43	5.8	0.7	240
	3/6	0745	7.41	184	140	67	6.8	1.3	≥ 2,400
		1400	7.43	206	100	55	5.8	0.9	188
		2100	7.63	243	150	73	5.1	1.1	1,600
A-2	3/6	0755	8.22	1,490	960	53	5.5	0.8	1,600
		1436	8.17	1,560	930	46	9.6	0.9	1,600
		2115	8.20	1,540	950	52	7.4	1.7	1,600
		2300	8.11	2,090	1,400	35	7.2	0.5	21
B-2	3/6	0755	8.30	1,540	1,000	49	6.4	0.5	920
		1430	8.16	1,380	810	72	9.4	0.8	1,600
		2110	8.12	1,370	810	75	7.4	0.2	≥ 2,400
		2300	8.26	2,120	1,400	34	8.0	0.5	69
C-2	3/6	1430	8.19	2,000	1,200	39	8.8	0.4	920
		2145	8.19	2,080	1,200	33	6.6	0.3	540
	3/7	0900	8.04	1,710	940	36	7.8	0.6	≥ 2,400

Station	Date	Time, hours	Ammonia N	Nitrate N	Kjeldahl N	Ortho P	Total P	Se	Cr	Cu	Pb	Mn	Ni	Zn
K-1	3/5	2254	1.4	0.88	2.0	0.15	0.46	0.07	0.016	< 0.01	0.028	0.18	0.07	0.04
	3/6	1250	0.52	1.6	1.7	0.16	0.36	0.01	0.012	< 0.01	0.007	0.09	0.03	0.01
		1400	0.67	1.2	2.0	0.15	0.36	0.06	0.019	0.01	0.012	0.10	0.06	0.01
		2240	1.4	0.83	0.97	0.17	0.31	0.01	0.014	0.01	0.018	0.11	< 0.03	0.01
K-2	3/5	2240	0.87	1.8	3.4	0.03	0.15	0.05	0.006	0.01	0.006	0.23	0.04	0.01
		0700	1.5	0.81	1.4	0.16	0.35	0.07	0.014	< 0.01	0.013	0.10	0.04	0.02
		1400	0.67	1.2	2.0	0.15	0.36	0.06	0.019	< 0.01	0.012	0.10	0.06	0.01
		2100	0.53	1.2	1.2	0.13	0.35	0.01	0.024	< 0.01	0.010	0.10	0.05	0.11
A-2	3/6	0755	1.5	0.69	3.4	< 0.01	0.21	0.04	0.006	0.02	0.007	0.40	0.03	0.03
		1430	0.29	1.0	2.3	0.01	0.22	0.07	0.010	< 0.01	< 0.005	0.49	0.04	0.01
		2115	0.43	1.0	2.2	< 0.01	0.16	0.06	0.012	< 0.01	0.005	0.47	0.03	< 0.01
		2300	0.82	0.30	1.9	< 0.01	0.13	0.03	< 0.005	< 0.01	< 0.005	0.74	< 0.03	< 0.01
B-2	3/6	0755	0.86	0.83	2.1	0.01	0.19	0.05	0.010	< 0.01	0.005	0.33	0.03	< 0.01
		1430	0.39	1.0	4.2	0.01	0.23	0.07	0.010	< 0.01	0.009	0.44	0.04	0.01
		2110	0.84	0.87	3.3	0.02	0.19	0.05	0.010	< 0.01	0.007	0.37	< 0.03	0.01
		2300	0.67	0.30	2.0	0.01	0.13	0.04	< 0.005	< 0.01	0.005	0.68	0.03	0.01
C-2	3/6	1430	0.14	2.0	2.4	< 0.01	0.13	0.05	0.010	0.01	0.005	0.94	< 0.03	< 0.01
		2145	0.02	0.59	1.6	< 0.01	0.17	0.05	0.009	< 0.01	< 0.005	0.65	< 0.03	0.03
	3/7	0900	0.37	0.78	1.8	0.01	0.39	0.05	0.010	< 0.01	0.005	0.46	< 0.04	0.04

[a] mg/l except as noted

TABLE B-5. 24-26 NOVEMBER 1985 STORM SUMMARY

FREMONT RAIN GAUGE ACWD# 1940	
Start Time	11/23 2215 h
Duration	19.36 hrs
Rainfall	1.14 in
Days since last storm	13

SAMPLING HOURS BY STATION

PERIOD	K-2	A-2	B-2	C-2
1	0.0-15.2	0.0-15.2	0.0-15.2	0.0-22.0
2	15.3-20.5	15.3-18.8	15.3-18.9	22.1-25.0
3	20.6-27.2	18.9-22.3	19.0-24.2	25.1-35.2
4	27.3-32.7	22.4-27.2	24.3-30.2	35.3-70
5	32.8-70	27.3-70	30.3-70	

REGULAR ANALYTICAL RESULTS[a]

Station	Period	Flow $CFx10^3$	pH Unit	EC umhos/cm	TDS	TSS	5-day BOD	Oil & Grease	Ammonia N	Nitrate N	Kjeldahl N
K-2	1	458.6	7.50	550	380	74	5.9	0.8	0.41	1.6	1.3
	2	441.8	7.31	350	170	97	5.5	2.1	0.48	1.6	1.4
	3	651.1	7.32	240	930	110	4.7	1.3	0.53	2.0	0.97
	4	356.1	7.34	240	130	84	4.7	1.6	0.69	4.0	1.0
	5	386.9	7.48	350	200	64	4.9	1.6	0.55	1.9	1.6
A-2	1	158.9	8.43	2,100	1,300	75	9.1	0.5	1.8	3.6	0.62
	2	240.2	8.42	2,100	11,000	61	7.2	1.9	1.2	4.2	1.2
	3	153.3	8.21	1,700	840	74	5.8	2.4	1.9	2.6	1.5
	4	254.1	8.13	1,350	660	88	5.1	1.7	1.8	2.2	1.2
	5	698.0	8.03	1,100	550	58	6.5	2.5	1.3	0.68	1.2
B-2	1	106.0	8.41	2,400	1,300	44	8.2	0.8	0.17	3.0	0.42
	2	160.2	8.27	1,890	140	67	6.3	1.7	0.11	3.6	1.5
	3	102.2	8.05	1,130	630	78	5.3	1.9	0.95	2.3	1.9
	4	169.4	8.03	1,420	710	120	5.2	1.3	0.14	2.2	1.7
	5	465.3	7.61	440	880	66	6.2	1.8	0.17	2.3	1.3
C-2	1	373.6	8.19	2,840	1,200	62	10	0.5	0.63	2.6	0.25
	2	176.7	8.28	2,480	1,400	39	7.7	1.3	0.33	2.2	0.49
	3	729.2	8.17	1,650	840	62	6.8	1.3	0.22	4.7	1.1
	4	871.9	7.97	1,700	790	51	7.0	1.0	0.28	2.6	1.1

Station	Period	Flow $CFx10^3$	Ortho P	Total P	Cd	Cr	Cu	Pb	Mn	Ni	Zn
K-2	1	458.6	0.22	0.42	0.003	0.058	<0.01	0.01	0.23	0.04	0.12
	2	441.8	0.24	0.41	0.002	0.052	0.02	<0.005	0.23	<0.03	0.13
	3	651.1	0.25	0.46	<0.002	0.056	0.01	<0.005	0.18	<0.03	0.10
	4	356.1	0.24	0.41	<0.002	0.044	<0.01	<0.005	0.19	<0.03	0.05
	5	386.9	0.22	0.35	0.004	0.040	0.01	<0.005	0.14	<0.03	0.10
A-2	1	158.9	0.08	0.24	0.007	0.017	0.01	<0.005	0.13	0.04	0.24
	2	240.2	0.07	0.25	<0.002	0.032	0.01	<0.005	0.30	<0.03	0.21
	3	153.3	0.09	0.31	0.004	0.037	0.02	0.009	0.27	0.04	0.21
	4	254.1	0.12	0.39	<0.002	0.052	0.02	<0.005	0.22	<0.03	0.09
	5	698.0	0.14	0.37	<0.002	0.048	0.02	<0.005	0.22	<0.03	0.12
B-2	1	106.0	0.08	0.31	0.011	0.016	0.02	<0.005	0.31	0.04	0.12
	2	160.2	0.08	0.28	0.007	0.052	<0.01	<0.005	0.21	<0.03	0.08
	3	102.2	0.10	0.36	0.010	0.046	0.01	<0.005	0.18	<0.03	0.10
	4	169.4	0.13	0.40	0.013	0.052	0.01	<0.005	0.28	0.11	0.31
	5	465.3	0.18	0.46	0.007	0.068	0.01	<0.005	0.24	0.04	0.11
C-2	1	373.6	0.09	0.34	0.004	<0.005	0.01	<0.005	0.45	<0.03	0.20
	2	176.7	0.08	0.28	<0.002	0.008	<0.01	<0.005	0.38	<0.03	0.04
	3	729.2	0.09	0.37	<0.002	0.011	0.01	<0.005	0.29	<0.03	0.08
	4	871.9	0.13	0.42	<0.002	0.036	<0.01	<0.005	0.26	<0.03	0.13

[a] mg/l except as noted

TABLE B-6. 3-5 JANUARY 1986 STORM SUMMARY

FREMONT RAIN GAUGE ACWD# 1940	
Start Time	1/3 2132 h
Duration	38 hrs
Rainfall	0.63 in
Days since last storm	4

SAMPLING HOURS BY STATION				
PERIOD	K-2	A-2	B-2	C-2
1	0.0-13.1	0.0-18.2	0.0-19.5	0.0-21.5
2	13.2-23.5	18.3-24.4	19.6-24.4	21.6-35.1
3	23.6-33.5	24.5-35.1	24.5-35.1	35.2-38.2
4	33.5-50	35.2-50	35.2-50	38.3-50

REGULAR ANALYTICAL RESULTS[a]

Station	Period	Flow $CF\times10^3$	pH Unit	EC umhos/cm	TDS	TSS	5-day BOD	Oil & Grease	Ammonia N	Nitrate N	Kjeldahl N
K-2	1	330.1	6.61	350	240	120	2.6	--	1.7	1.6	2.3
	2	528.5	7.39	350	220	72	6.0	--	1.7	1.6	1.5
	3	35.0	7.55	460	270	66	3.5	--	1.6	2.1	2.0
	4	280.5	7.75	570	310	48	3.3	--	1.1	2.8	2.5
A-2	1	209.3	7.45	1,300	670	52	8.9	--	0.88	2.8	2.7
	2	118.0	8.05	1,200	650	54	7.2	--	0.59	2.9	2.3
	3	110.5	8.05	1,000	730	48	3.3	--	0.56	3.2	1.5
	4	33.9	8.20	1,200	520	46	4.2	--	0.53	2.6	1.5
B-2	1	157.1	8.12	1,200	630	32	6.0	--	0.55	3.9	3.1
	2	61.1	8.08	1,000	550	74	3.3	--	0.85	3.1	1.5
	3	73.7	8.05	870	450	66	4.2	--	1.1	2.5	2.5
	4	22.0	8.05	870	750	64	3.0	--	0.91	2.3	1.4
C-2	1	172.4	7.78	1,400	450	14	1.8	--	0.94	2.3	1.2
	2	595.7	7.78	1,400	590	18	1.8	--	0.96	2.4	2.7
	3	52.0	7.55	1,400	730	24	3.3	--	0.80	2.4	1.1
	4	190.0	7.85	1,400	700	10	4.8	--	1.2	2.4	1.5

Station	Period	Flow $CF\times10^3$	Ortho P	Total P	Cd	Cr	Cu	Pb	Mn	Ni	Zn
K-2	1	330.1	0.21	0.45	<0.002	0.05	0.02	0.020	0.21	0.05	0.04
	2	528.5	0.46	0.84	<0.002	0.03	0.02	0.012	0.25	0.03	0.07
	3	35.0	0.19	0.31	<0.002	0.04	0.01	0.009	0.12	0.03	0.01
	4	280.5	0.17	0.27	<0.002	0.04	0.01	0.019	0.17	<0.03	0.02
A-2	1	209.3	0.09	0.31	<0.002	0.03	0.02	0.007	0.16	<0.03	0.01
	2	118.0	0.08	0.28	<0.002	0.03	0.03	0.008	0.18	0.03	0.04
	3	110.5	0.09	0.27	<0.002	0.02	0.03	0.007	0.16	<0.03	<0.01
	4	33.9	0.12	0.31	0.003	0.02	0.02	0.006	0.16	<0.03	0.01
B-2	1	157.1	0.09	0.24	0.007	0.03	0.02	0.005	0.18	0.03	<0.01
	2	61.1	0.12	0.28	0.006	0.03	0.01	<0.005	0.10	0.04	0.02
	3	73.7	0.12	0.34	0.011	0.05	0.02	0.005	0.17	0.06	0.05
	4	22.0	0.12	0.35	0.003	0.04	0.02	0.014	0.18	0.04	0.01
C-2	1	172.4	0.09	0.13	<0.002	0.02	0.01	<0.005	0.24	<0.03	0.01
	2	595.7	0.09	0.15	0.003	0.01	0.02	<0.005	0.24	<0.03	0.02
	3	52.0	0.09	0.18	0.003	0.02	0.02	<0.005	0.22	0.04	<0.01
	4	190.0	0.09	0.15	0.002	0.01	0.02	<0.005	0.16	0.03	0.03

[a] mg/l except as noted

TABLE B-7. 29-30 JANUARY 1986 STORM SUMMARY

FREMONT RAIN GAUGE ACWD# 1940

Start Time	1/29 0755 h
Duration	12.0 hrs
Rainfall	0.35 in
Days since last storm	12

SAMPLING HOURS BY STATION

PERIOD	K-2	A-2	B-2	C-2
1	0.0-4.1	0.0-8.0	0.0-8.0	0.0-12.0
2	4.2-9.0	8.1-11.1	8.1-11.1	12.1-15.0
3	9.1-12.0	11.2-13.0	11.2-13.0	15.1-17.1
4	12.1-16.0	13.1-15.1	13.1-15.1	17.2-30
5	16.1-30	15.2-30	15.2-30	

REGULAR ANALYTICAL RESULTS[a]

Station	Period	Flow $CFx10^3$	pH Unit	EC umhos/cm	TDS	TSS	5-day BOD	Oil & Grease	Ammonia N	Nitrate N	Kjeldahl N
K-2	1	5.1	8.33	2,130	1,400	28	2.7	<0.5	0.33	3.4	0.52
	2	90.3	8.34	2,240	1,300	61	1.9	0.6	0.40	3.7	0.27
	3	138.5	8.38	1,970	1,100	36	1.7	0.6	0.43	3.7	1.5
	4	124.4	8.01	910	520	52	2.9	0.7	0.57	1.9	1.8
	5	205.1	7.86	640	300	74	3.4	1.8	1.1	2.6	2.1
A-2	1	4.3	8.45	1,440	880	34	5.8	<0.5	1.6	3.2	1.6
	2	47.8	8.40	1,280	920	22	5.3	<0.5	1.6	3.5	2.0
	3	30.9	8.42	1,490	910	36	5.6	0.6	0.98	2.9	2.9
	4	35.7	8.34	1,490	830	38	4.9	0.6	0.38	4.2	1.5
	5	137.9	8.19	1,390	860	36	5.0	0.0	0.54	3.4	1.3
B-2	1	2.9	8.22	1,280	790	15	4.4	0.6	0.81	1.3	2.7
	2	31.9	8.14	1,390	800	7	5.2	<0.5	0.84	1.4	2.4
	3	20.6	8.24	1,330	940	11	4.9	0.8	0.82	1.3	1.5
	4	23.8	8.22	1,280	780	15	4.6	0.5	0.78	1.4	3.1
	5	91.9	8.00	1,280	790	18	6.3	0.0	0.55	2.4	2.4
C-2	1	12.6	7.76	1,700	1,000	14	4.3	0.5	0.37	1.4	2.9
	2	34.0	7.99	1,390	940	14	3.3	<0.5	0.46	2.9	0.61
	3	55.2	7.69	1,600	970	29	4.7	<0.5	1.1	1.4	1.9
	4	197.6	7.62	1,700	980	28	5.0	0.5	0.61	1.4	2.4

Station	Period	Flow $CFx10^3$	Ortho P	Total P	Cd	Cr	Cu	Pb	Mn	Ni	Zn
K-2	1	5.1	0.06	0.15	<0.002	0.02	0.01	<0.005	0.20	<0.03	<0.01
	2	90.3	0.08	0.15	<0.002	0.02	0.01	<0.005	0.20	0.03	<0.01
	3	138.5	0.09	0.16	<0.002	0.01	0.01	<0.005	0.12	0.03	<0.01
	4	124.4	0.13	0.29	<0.002	0.03	0.01	0.007	0.12	0.03	<0.01
	5	205.1	0.15	0.37	<0.002	0.03	0.02	0.008	0.14	0.03	0.04
A-2	1	4.3	0.09	0.20	<0.002	0.02	0.01	0.006	0.35	<0.03	0.04
	2	47.8	0.06	0.14	<0.002	0.02	0.01	<0.005	0.29	<0.03	<0.01
	3	30.9	0.13	0.21	<0.002	0.02	0.01	<0.005	0.33	<0.03	<0.01
	4	35.7	0.10	0.20	<0.002	0.02	0.01	0.007	0.31	0.03	<0.01
	5	137.9	0.10	0.17	<0.002	0.01	0.01	0.005	0.20	<0.03	0.04
B-2	1	2.9	0.13	0.18	<0.002	0.01	0.01	0.005	0.43	<0.03	<0.01
	2	31.9	0.09	0.19	<0.002	0.01	0.01	<0.005	0.51	<0.03	0.05
	3	20.6	0.09	0.20	<0.002	0.01	0.01	<0.005	0.31	0.03	<0.01
	4	23.8	0.12	0.15	0.002	0.01	0.01	<0.005	0.30	0.03	<0.01
	5	91.9	0.10	0.22	<0.002	0.02	0.01	<0.005	0.28	0.04	<0.01
C-2	1	12.6	0.06	0.14	<0.002	0.01	0.01	<0.005	0.41	<0.03	<0.01
	2	34.0	0.08	0.13	<0.002	0.02	0.01	0.010	0.36	0.03	0.01
	3	55.2	0.08	0.16	<0.002	0.01	0.01	<0.005	0.48	0.03	<0.01
	4	197.6	0.08	0.17	<0.002	0.02	0.01	0.005	0.63	0.04	0.01

[a] mg/l except as noted

TABLE B-8. 31 JANUARY - 1 FEBRUARY 1986 STORM SUMMARY

FREMONT RAIN GAUGE ACWD# 1940	
Start Time	1/31 0727 hr
Duration	3.0 hrs
Rainfall	0.55 in
Days since last storm	0

SAMPLING HOURS PERIOD	K-2	A-2	B-2	C-2
	BY STATION			
1	0.0-3.0	0.0-3.0	0.0-3.0	0.0-7.0
2	3.1-7.0	3.1-7.0	3.1-7.0	7.1-11.0
3	7.1-9.0	7.1-11.0	7.1-11.0	11.1-16.0
4	9.1-21.0	11.1-23.0	11.1-23.0	16.1-25.0
5	21.1-50	23.1-50	23.1-50	25.1-50

REGULAR ANALYTICAL RESULTS[a]

Station	Period	Flow CFx10^3	pH Unit	EC umhos/cm	TDS	TSS	5-day BOD	Oil & Grease	Ammonia N	Nitrate N	Kjeldahl N
K-2	1	3.5	--	--	360	77	--	--	--	1.2	1.8
	2	302.2	--	--	600	35	--	--	--	1.7	2.3
	3	238.6	--	--	--	--	--	--	--	--	--
	4	713.9	--	--	410	130	--	--	--	1.5	3.2
	5	154.5	--	--	580	24	--	--	--	1.6	2.1
A-2	1	33.6	--	--	990	38	--	--	--	2.4	2.1
	2	23.9	--	--	820	48	--	--	--	2.6	1.7
	3	125.2	--	--	760	42	--	--	--	2.6	1.6
	4	371.5	--	--	490	98	--	--	--	1.9	1.8
	5	273.8	--	--	520	170	--	--	--	1.9	2.1
B-2	1	22.4	--	--	670	52	--	--	--	2.1	1.8
	2	15.9	--	--	530	86	--	--	--	1.5	1.5
	3	83.5	--	--	400	100	--	--	--	1.6	2.1
	4	247.7	--	--	470	84	--	--	--	1.5	1.8
	5	182.5	--	--	620	70	--	--	--	1.5	2.0
C-2	1	95.8	--	--	1,000	20	4.7	--	0.82	1.9	2.1
	2	208.7	--	--	880	16	3.7	--	0.59	1.9	2.6
	3	346.1	--	--	820	31	2.7	--	0.54	1.9	3.1
	4	273.0	--	--	680	45	3.7	--	1.1	1.9	1.5
	5	456.3	--	--	620	50	5.4	--	0.76	2.1	1.8

Station	Period	Flow CFx10^3	Ortho P	Total P	Cd	Cr	Cu	Pb	Mn	Ni	Zn
K-2	1	3.5	0.16	0.31	<0.002	0.03	0.02	0.011	0.12	<0.03	0.14
	2	302.2	0.16	0.63	<0.002	0.09	0.03	0.011	0.36	0.08	0.12
	3	238.6	--	--	--	--	--	--	--	--	--
	4	713.9	0.22	0.85	<0.002	0.11	0.03	0.012	0.43	0.07	0.11
	5	154.5	0.19	0.53	<0.002	0.07	0.01	0.020	0.20	<0.03	0.10
A-2	1	33.6	0.10	0.18	<0.002	0.03	0.01	0.014	0.22	<0.03	0.08
	2	23.9	0.08	0.17	<0.002	0.03	0.02	0.024	0.16	<0.03	0.06
	3	125.2	0.08	0.19	<0.002	0.03	0.01	0.015	0.16	<0.03	0.09
	4	371.5	0.09	0.73	<0.002	0.08	0.03	0.016	0.34	0.04	0.13
	5	273.8	0.10	0.53	<0.002	0.03	0.02	0.020	0.26	<0.03	0.11
B-2	1	22.4	0.09	0.22	<0.002	0.04	0.01	0.022	0.14	<0.03	0.07
	2	15.9	0.08	0.28	<0.002	0.05	0.01	0.011	0.16	<0.03	0.07
	3	83.5	0.10	0.18	<0.002	0.08	0.01	0.014	0.19	0.03	0.64
	4	247.7	0.16	0.52	0.002	0.08	0.02	0.011	0.32	0.06	0.12
	5	182.5	0.15	0.56	<0.002	0.08	0.02	0.013	0.34	0.04	0.12
C-2	1	95.8	0.08	0.18	<0.002	0.01	0.01	<0.005	0.45	<0.03	0.03
	2	208.7	0.08	0.19	<0.002	0.01	0.01	<0.005	0.19	<0.03	0.01
	3	346.1	0.08	0.20	<0.002	0.02	0.01	<0.005	0.22	<0.03	<0.01
	4	273.0	0.09	0.28	<0.002	0.01	0.01	0.007	0.36	<0.03	0.07
	5	456.3	0.10	0.30	<0.002	0.03	0.01	0.005	0.27	0.04	0.03

[a] mg/l except as noted

TABLE B-9. 12-13 FEBRUARY 1986 STORM SUMMARY

FREMONT RAIN GAUGE ACWD# 1940	
Start Time	2/12 1236 h
Duration	10 hrs
Rainfall	0.59 in
Days since last storm	9

SAMPLING HOURS BY STATION

PERIOD	K-2	A-2	B-2	C-2
1	0.0-9.9	0.0-10.4	0.0-10.4	0.0-23.9
2	10.0-13.4	10.5-13.4	10.5-13.4	24.0-36.0
3	13.5-32.0	13.5-23.7	13.5-23.7	37.0-40
4	32.1-40	23.8-36.0	23.8-36.0	
5		37.0-40	37.0-40	

REGULAR ANALYTICAL RESULTS[a]

Station	Period	Flow CFx10^3	pH Unit	EC umhos/cm	TDS	TSS	5-day BOD	Oil & Grease	Ammonia N	Nitrate N	Kjeldahl N
K-2	1	9.4	8.24	2,610	1,600	1.9	1.3	--	0.56	9.5	0.96
	2	269.5	8.34	2,730	1,600	28	2.1	--	0.16	11.1	1.1
	3	828.5	7.93	710	370	98	5.1	--	0.24	2.9	2.5
	4	57.6	7.38	340	200	74	1.6	0.9	0.57	1.7	2.2
A-2	1	6.3	7.97	1,310	790	64	3.8	<0.5	0.64	3.5	1.8
	2	66.7	8.17	1,190	730	68	3.8	<0.5	0.42	3.9	2.3
	3	396.3	8.11	1,420	720	69	2.6	<0.5	0.29	4.0	1.5
	4	100.2	8.00	1,190	700	59	3.9	<0.5	0.88	3.6	2.0
	5	42.6	7.81	1,210	580	55	2.3	<0.5	0.75	3.5	1.4
B-2	1	4.2	8.12	1,520	850	45	4.5	<0.5	0.40	4.6	1.0
	2	44.4	8.27	1,540	870	39	2.9	0.7	0.14	4.1	1.1
	3	263.9	8.23	1,610	941	38	2.1	<0.5	0.15	4.9	1.7
	4	66.7	8.11	1,450	760	68	4.5	<0.5	0.24	4.4	2.2
	5	28.4	7.89	1,140	520	45	2.3	1.1	0.34	3.9	2.0
C-2	1	588.1	7.65	1,560	890	41	4.2	<0.5	0.35	1.7	3.1
	2	241.4	7.72	1,720	930	37	4.5	<0.5	0.85	1.5	2.8
	3	168.1	7.88	1,630	890	32	4.8	<0.5	0.26	2.5	2.0

Station	Period	Flow CFx10^3	Ortho P	Total P	Cd	Cr	Cu	Pb	Mn	Ni	Zn
K-2	1	9.4	0.17	0.18	<0.002	0.02	0.01	<0.005	0.12	<0.03	0.02
	2	269.5	0.12	0.17	<0.002	0.02	0.02	0.007	0.12	0.04	0.03
	3	828.5	0.42	0.71	<0.002	0.05	0.02	0.011	0.19	0.05	0.07
	4	57.6	0.20	0.20	<0.002	0.04	0.02	0.009	0.14	0.04	0.03
A-2	1	6.3	0.15	0.31	<0.002	0.03	0.02	0.005	0.35	0.04	0.01
	2	66.7	0.13	0.30	<0.002	0.03	0.02	<0.005	0.33	0.05	0.04
	3	396.3	0.14	0.32	<0.002	0.03	0.02	<0.005	0.31	0.03	0.02
	4	100.2	0.14	0.35	<0.002	0.04	0.02	<0.005	0.24	0.04	0.03
	5	42.6	0.14	0.24	<0.002	0.03	0.01	<0.005	0.18	0.03	<0.01
B-2	1	4.2	0.17	0.32	<0.002	0.03	0.01	0.005	0.26	0.03	0.03
	2	44.4	0.18	0.32	<0.002	0.02	0.01	<0.005	0.23	0.03	<0.01
	3	263.9	0.18	0.30	<0.002	0.02	0.01	<0.005	0.21	0.04	<0.01
	4	66.7	0.15	0.32	<0.002	0.03	0.01	0.016	0.16	0.03	0.07
	5	28.4	0.13	0.39	<0.002	0.02	0.01	<0.005	0.10	<0.03	0.02
C-2	1	588.1	0.09	0.14	<0.002	0.01	0.01	<0.005	1.1	0.03	<0.01
	2	241.4	0.08	0.15	<0.002	0.02	0.01	<0.005	1.1	0.05	<0.01
	3	168.1	0.09	0.17	<0.002	0.02	0.01	<0.005	0.45	0.04	<0.01

a mg/l except as noted

TABLE B-10. 14-15 FEBRUARY 1986 STORM SUMMARY

FREMONT RAIN GAUGE ACWD# 1940	
Start Time	2/14 0425 h
Duration	27 hrs
Rainfall	1.14 in
Days since last storm	2

SAMPLING HOURS BY STATION

PERIOD	K-2	A-2	B-2	C-2
1	0.0-3.9	0.0-4.6	0.0-4.6	0.0-5.1
2	4.0-9.1	4.7-7.9	4.7-7.9	5.2-13.8
3	9.2-17.6	8.0-13.8	8.0-13.8	13.9-24.1
4	17.7-24.1	13.9-25.6	13.9-25.6	24.1-30.6
5	24.2-36	25.7-36	25.7-36	30.7-36

REGULAR ANALYTICAL RESULTS[a]

Station	Period	Flow CFx10^3	pH Unit	EC umhos/cm	TDS	TSS	5-day BOD	Oil & Grease	Ammonia N	Nitrate N	Kjeldahl N
K-2	1	85.6	7.62	520	230	92	2.7	**	0.21	1.6	2.1
	2	573.0	7.78	860	1,200*	65	2.6	**	0.10	3.9	1.1
	3	1,255.4	7.78	460	470*	110	2.4	**	0.11	1.8	2.5
	4	217.3	7.25	460	410**	200	6.2	0.5	0.19	1.5	2.5
	5	348.4	7.60	670	520**	89	3.8	<0.5	0.41	2.6	1.5
A-2	1	43.3	7.83	1,140	570	59	2.5	0.8	0.31	3.9	2.5
	2	125.6	7.89	1,160	590	70	2.4	0.9	0.37	3.3	2.0
	3	420.5	7.90	1,120	530	83	2.6	0.8	0.46	3.2	2.5
	4	651.3	7.68	970	460	87	2.5	<0.5	0.25	2.9	2.9
	5	208.6	7.55	550	300	88	3.2	<0.5	0.63	4.2	3.5
B-2	1	28.9	8.05	1,310	620	44	2.7	0.6	0.28	3.2	1.1
	2	83.7	7.99	1,240	600	64	2.4	<0.5	0.53	4.1	1.3
	3	280.3	7.90	970	470	120	2.2	0.6	0.19	2.9	2.7
	4	434.2	7.65	540	280	120	3.0	0.9	0.33	1.7	3.6
	5	139.1	7.60	670	340	150	3.3	<0.5	0.49	1.5	3.8
C-2	1	75.3	7.90	1,580	800	24	2.4	0.6	0.92	3.4	1.8
	2	614.6	7.88	1,650	840	24	2.5	<0.5	0.32	3.3	2.4
	3	1,096.2	7.80	1,660	830	37	2.4	<0.5	0.56	2.9	3.0
	4	331.6	7.52	1,120	560	65	2.8	0.9	0.69	3.4	2.3
	5	228.1	7.57	1,020	640	55	2.8	0.5	0.67	2.1	3.0

Station	Period	Flow CFx10^3	Ortho P	Total P	Cd	Cr	Cu	Pb	Mn	Ni	Zn
K-2	1	85.6	0.15	0.43	<0.002	0.04	0.02	<0.005	0.16	0.06	0.03
	2	573.0	0.14	0.32	<0.002	0.02	0.01	<0.005	0.10	0.05	0.01
	3	1,255.4	0.15	0.56	<0.002	0.07	0.02	<0.005	0.24	0.05	0.03
	4	217.3	0.71	1.4	<0.002	0.09	0.02	<0.005	0.36	0.07	0.03
	5	348.4	0.40	0.65	<0.002	0.04	0.01	<0.005	0.13	<0.03	0.03
A-2	1	43.3	0.13	0.38	<0.002	0.02	0.01	<0.005	0.20	0.03	<0.01
	2	125.6	0.11	0.34	<0.002	0.03	0.01	<0.005	0.22	0.03	<0.01
	3	420.5	0.13	0.34	<0.002	0.04	0.01	<0.005	0.22	0.04	<0.01
	4	651.3	0.13	0.38	<0.002	0.01	0.01	<0.005	0.18	0.04	0.01
	5	208.6	0.42	3.0	<0.002	0.07	0.02	0.008	0.31	0.07	0.03
B-2	1	28.9	0.15	0.37	<0.002	0.01	0.01	<0.005	0.10	<0.03	<0.01
	2	83.7	0.14	0.37	<0.002	0.03	0.01	<0.005	0.12	0.04	<0.01
	3	280.3	0.21	3.4	<0.002	0.04	0.01	<0.005	0.14	0.05	<0.01
	4	434.2	0.32	0.80	<0.002	0.01	<0.01	<0.005	0.02	<0.03	<0.01
	5	139.1	0.51	1.2	<0.002	0.05	0.01	0.009	0.28	0.06	0.01
C-2	1	75.3	0.14	0.41	<0.002	0.01	0.01	<0.005	0.35	<0.03	0.02
	2	614.6	0.10	0.23	<0.002	0.02	0.01	<0.005	0.46	0.05	<0.01
	3	1,096.2	0.10	0.24	<0.002	0.01	0.01	<0.005	0.28	<0.03	0.01
	4	331.6	0.15	0.36	<0.002	0.03	0.02	<0.005	0.18	0.04	<0.01
	5	228.1	0.18	0.41	<0.002	0.03	0.02	<0.005	0.30	0.03	0.02

[a] mg/l except as noted

TABLE B-11. 7-8 MARCH 1986 STORM SUMMARY

FREMONT RAIN GAUGE ACWD# 1940	
Start Time	3/73 1238 h
Duration	2.82 hrs
Rainfall	1.06 in
Days since last storm	15

SAMPLING HOURS BY STATION

PERIOD	K-2	A-2	B-2	C-2
1	0.0-11.9	0.0-11.9	0.0-11.9	0.0-12.9
2	12.0-15.0	12.0-15.9	12.0-15.9	13.0-16.9
3	15.1-24.4	16.0-22.6	16.0-22.6	17.0-23.4
4	24.5-28.4	22.7-30.9	22.7-30.9	23.5-30.9
5	28.5-50	31.0-50	31.0-50	30.9-50

REGULAR ANALYTICAL RESULTS[a]

Station	Period	Flow $CFx10^3$	pH Unit	EC umhos/cm	TDS	TSS	5-day BOD	Oil & Grease	Ammonia N	Nitrate N	Kjeldahl N
K-2	1	194.0	8.36	2,300	1,300	23	1.2	--	0.51	8.2	0.63
	2	367.7	8.31	2,660	1,300	30	1.8	--	0.51	10	0.15
	3	494.2	7.78	850	420	54	6.8	--	0.36	4.0	1.2
	4	117.6	7.43	300	150	57	6.0	--	0.43	1.3	1.2
	5	113.3	7.70	390	230	72	6.3	--	1.2	1.1	2.3
A-2	1	12.8	8.13	2,270	1,200	30	9.2	--	0.34	4.7	3.0
	2	224.6	8.27	2,270	1,300	19	9.2	--	0.38	4.9	2.6
	3	241.8	8.08	2,540	1,300	10	11	--	0.50	4.8	2.3
	4	160.5	8.22	2,300	1,100	16	9.2	--	0.27	5.1	1.8
	5	149.2	8.02	1,330	680	70	9.5	--	0.14	4.6	2.0
B-2	1	8.5	8.39	2,400	1,400	12	9.2	--	0.18	5.5	2.5
	2	149.8	8.47	2,450	1,400	11	7.0	--	0.32	6.1	2.1
	3	161.2	8.32	2,910	1,500	15	7.1	--	0.34	7.0	2.3
	4	107.0	8.08	1,570	730	31	8.9	--	0.14	4.8	2.2
	5	99.5	7.69	730	320	78	7.8	--	0.33	2.0	3.0
C-2	1	120.4	7.76	2,340	1,400	13	3.5	--	0.33	1.9	1.7
	2	120.3	7.64	2,790	1,600	17	5.5	--	0.38	1.7	0.41
	3	507.6	7.92	2,790	1,500	22	6.1	--	0.50	4.2	2.3
	4	396.0	8.20	2,790	1,400	13	7.0	--	0.42	4.9	1.4
	5	351.5	8.01	1,630	870	27	7.5	--	0.23	5.1	1.2

Station	Period	Flow $CFx10^3$	Ortho P	Total P	Cd	Cr	Cu	Pb	Mn	Ni	Zn
K-2	1	194.0	0.04	0.12	<0.002	0.01	0.01	<0.005	0.06	<0.03	0.03
	2	367.7	0.07	0.18	<0.002	0.01	0.01	<0.005	0.07	<0.03	0.07
	3	494.2	0.14	0.22	<0.002	0.04	0.01	0.008	0.12	<0.03	0.04
	4	117.6	0.24	0.35	<0.002	0.02	0.02	<0.005	0.10	<0.03	0.04
	5	113.3	24	0.78	<0.002	0.17	0.05	<0.005	0.72	0.14	0.10
A-2	1	12.8	0.05	0.20	<0.002	0.01	0.01	<0.005	0.49	<0.03	0.03
	2	224.6	0.07	0.16	<0.002	0.01	0.02	<0.005	0.51	<0.03	0.03
	3	241.8	0.04	0.14	<0.002	0.01	0.01	<0.005	0.76	<0.03	0.02
	4	160.5	0.02	0.11	<0.002	0.01	0.01	<0.005	0.49	<0.03	0.03
	5	149.2	0.07	0.16	<0.002	0.02	0.01	<0.005	0.30	<0.03	0.03
B-2	1	8.5	0.01	0.14	0.004	0.01	0.01	<0.005	0.16	<0.03	0.03
	2	149.8	0.02	0.14	0.002	0.01	0.02	<0.005	0.16	<0.03	0.04
	3	161.2	0.04	0.18	<0.002	0.01	0.01	<0.005	0.22	<0.03	0.03
	4	107.0	0.05	0.17	<0.002	0.02	0.01	<0.005	0.14	<0.03	0.03
	5	99.5	0.22	0.30	<0.002	0.03	0.02	<0.005	0.14	0.03	0.04
C-2	1	120.4	0.45	0.60	<0.002	0.01	0.01	<0.005	1.0	<0.03	0.03
	2	120.3	0.16	0.37	<0.002	0.01	0.01	<0.005	1.4	<0.03	0.03
	3	507.6	0.07	0.20	<0.002	0.01	0.01	<0.005	0.98	<0.03	0.02
	4	396.0	0.022	0.18	<0.002	0.01	0.01	<0.005	0.66	<0.03	0.02
	5	351.5	0.05	0.19	<0.002	0.01	0.01	<0.005	0.28	<0.03	0.01

[a] mg/l except as noted

Table C-1. FISH ANALYSES, 8 November 1984
COYOTE HILLS MARSH

Parameter	n	mean length (mm)	mean wt (kg)	Cd	Cr	Cu (ppm, wet weight)	Pb	Zn	Mn
Gambusia									
System A	--	--	--	0.06	0.03	2.3	a	32.4	9.4
System B	--	--	--	--	--	--	--	--	--
System C	--	--	--	0.01	0.03	1.7	a	32.4	10.0
TSM Elevated Data Level (EDL)									
85th percentile (liver)				0.43	0.03	6.91	0.2	30	--
95th percentile (liver)				2.1	0.10	28.9	0.2	38	--

* Exceeds TSM EDL 85th percentile (liver)
** Exceeds TSM EDL 95th percentile (liver)
a Insufficient sample for analysis
-- No sample taken or no value available

Table C-2. FISH ANALYSES, 2 April 1985
COYOTE HILLS MARSH

Parameter	n	mean length (mm)	mean wt. (kg)	Cd	Cr	Cu (ppm, wet weight)	Pb	Zn	Mn
Blackfish									
System A	3	191	.83	a	a	9.7*	a	80.**	12
System B	2	205	1.77	a	4.4**	5.8	a	34.*	86
System C	3	163.4	.829	a	a	a	a	35.*	11
Carp									
System A	2	165	1.10	0.04	0.07*	13.*	0.1	170.**	4.3
System B	--	--	--	--	--	--	--	--	--
System C	1	300	5.86	0.02	0.07*	8.1*	0.1	57.**	9.6
TSM Elevated Data Level (EDL)									
85th percentile (liver)				0.43	0.03	6.91	0.2	30	--
95th percentile (liver)				2.1	0.10	28.9	0.2	38	--

For explanation of footnotes, refer to Table C-1.

Table C-3. FISH ANALYSES, 5 June 1985
COYOTE HILLS MARSH

Parameter	n	mean length (mm)	mean wt. (kg)	Cd	Cr	Cu	Pb	Zn	Mn
						(ppm, wet weight)			
Blackfish									
System A	2	271.5	2.05	a	a	6.9	a	24	7
System B	--	--	--	--	--	--	--	--	--
System C	3	313.0	4.08	a	2.8**	3.3	a	18	12
Carp									
System A	1	--	--	a	0.05*	22.*	0.2	237.**	16
System B	1	--	--	a	4.4**	8.3*	a	250.**	11
System C	3	--	--	a	0.22**	2.7	0.1	21.5	14
Stickleback									
System A	35	55	1.98	a	0.1	3	0.1	26.8	18
System B	26	50	1.96	a	1	3.9	0.83	37	28
System C	44	63	2.1	0.01	0.47	2.3	0.1	27.9	18
TSM Elevated Data Level (EDL)									
85th percentile (liver)				0.43	0.03	6.91	0.2	30	--
95th percentile (liver)				2.1	0.10	28.9	0.2	38	--

For explanation of footnotes, refer to Table C-1.

Table C-4. FISH ANALYSES, 11 July 1985
COYOTE HILLS MARSH

Parameter	n	mean length (mm)	mean wt. (kg)	Cd	Cr	Cu	Pb	Zn	Mn
						(ppm, wet weight)			
Gambusia									
System A	--	--	--	--	--	--	--	--	--
System B	--	--	--	--	--	--	--	--	--
System C	6	--	--	a	0.98	3.2	0.82	37	19
Stickleback									
System A	--	--	--	--	--	--	--	--	--
System B	5	45	1.74	a	0.79	16.	0.98	43	20
System C	4	47	2.4	a	1.1	2.7	0.9	37	24
Sculpin									
System A	3	65	3.93	a	1.2	1.1	1	18	6.4
System B	8	60	3.70	a	0.62	0.94	0.77	17	6.7
System C	9	60	3.0	a	0.5	1	0.63	20	12
TSM Elevated Data Level (EDL)									
85th percentile (liver)				0.43	0.03	6.91	0.2	30	--
95th percentile (liver)				2.1	0.10	28.9	0.2	38	--

For explanation of footnotes, refer to Table C-1.

Table C-5. FISH ANALYSES, 10 October 1985
COYOTE HILLS MARSH

Parameter	n	mean length (mm)	mean wt. (kg)	Cd	Cr	Cu (ppm, wet weight)	Pb	Zn	Mn
Blackfish									
System A	2	209	1.86	a	a	15.*	a	29.	a
System B	3	231.7	2.54	a	1.2**	24.*	a	32.*	2.8
System C	3	238	2.62	a	a	13.*	a	26.	2
Carp									
System A	2	230	4.06	0.02	0.05*	5.8	0.1	138.**	6.9
System B	2	222	2.22	a	1.6**	9.6*	a	85.**	1.7
System C	2	192	1.92	--	--	--	--	--	--
Gambusia									
System A	20	36.6	0.7	a	2.2	2.1	0.93	27	11
System B	39	36.6	.67	a	0.69	1.4	0.87	28	9.2
System C	22	35.5	.51	a	0.05	1	a	21	7
Stickleback									
System A	33	40	.11	0.18	0.05	28	0.2	155	1.3
System B	27	38	.38	a	1	2.7	0.84	41	29
System C	25	49	.49	0.01	0.29	2.7	0.1	32	23
TSM Elevated Data Level (EDL)									
85^{th} percentile (liver)				0.43	0.03	6.91	0.2	30	--
95^{th} percentile (liver)				2.1	0.10	28.9	0.2	38	--

For explanation of footnotes, refer to Table C-1.

Table C-6. FISH ANALYSES, 21 November 1985
COYOTE HILLS MARSH

Parameter	n	mean length (mm)	mean wt. (kg)	Cd	Cr	Cu (ppm, wet weight)	Pb	Zn	Mn
Gambusia									
System A	--	--	--	a	0.68	1.6	0.85	40	5.1
System B	--	--	--	a	2.5	3	2.1	120	28
System C	--	--	--	--	--	--	--	--	--
Sculpin									
System A	20	--	--	a	0.68	0.91	0.86	13	6.1
System B	--	--	--	a	1	0.9	0.85	18	8.3
System C	--	--	--	a	0.77	1	0.64	23	15
TSM Elevated Data Level (EDL)									
85^{th} percentile (liver)				0.43	0.03	6.91	0.2	30	--
95^{th} percentile (liver)				2.1	0.10	28.9	0.2	38	--

For explanation of footnotes, refer to Table C-1.

Table C-7. FISH ANALYSES, 27 November 1985
COYOTE HILLS MARSH

Parameter	n	mean length (mm)	mean wt. (kg)	Cd	Cr	Cu	Pb	Zn	Mn
				(ppm, wet weight)					
Gambusia									
South Marsh	35	--	--	a	0.78	2.2	0.98	34.	9.3
Sculpin									
South Marsh	--	--	.13	a	1.9	a	a	18	7.2
TSM Elevated Data Level (EDL)									
85th percentile (liver)				0.43	0.03	6.91	0.2	30	--
95th percentile (liver)				2.1	0.10	28.9	0.2	38	--

For explanation of footnotes, refer to Table C-1.

Table C-8. FISH ANALYSES, 15 October 1986
COYOTE HILLS MARSH (ppm, wet weight)

Parameter	n	$\bar{x}$	s	Cd	Cr	Cu	Pb	Zn	Se
Sediment				0.67	67	16	9.4	35	<0.5
Blackfish									
Length, mm	13	189.23	14.10						
Weight, kg	13	.975							
Liver				0.25*	2.0**	25.*	3.5*	28	<0.5
Flesh				0.25	<1.0	4.0	3.5***	5	<0.5
Carp									
Length,mm	6	305.	19.28						
Weight, kg	6	5.49	0.86						
Liver				0.75*	1.0**	22.0*	9.0*	200.**	0.60
Flesh				0.62***	<1.0	3.0	7.0***	7.5	<0.5
Gambusia									
Length,mm	25	33.6	14.77						
Weight, gm	25	0.95							
Whole Fish	DUST Marsh			0.25	1.0	22	<1.2	34	<0.5
	South Marsh A			<0.25	<1.0	<1.2	<1.2	22	<0.5
	South Marsh B			<0.25	<1.0	1.2	<1.2	24	<0.5
Stickleback									
Length,mm	32	45							
Weight, gm	32	0.81							
Whole Fish				0.25	1.0	6.5	2.5	38	<0.5
Median International Standard									
(fish flesh)				.30	1.0	20	2.0	45	2.0
TSM Elevated Data Level (EDL)									
85th percentile (liver)				0.43	0.03	6.91	0.2	30	3.5
95th percentile (liver)				2.1	0.10	28.9	0.2	38	5.8

* Exceeds TSM EDL 85th percentile (liver)
** Exceeds TSM EDL 95th percentile (liver)
*** Exceeds Median International Standard
Note: Fish samples were collected in System B unless otherwise noted.

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